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FINAL REPORT

DUCT FLOW NONUNIFORMITIES FOR SPACE SHUTTLE MAIN ENGINE (SSME)

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Contract NAS8-34507

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FOREWORD

This report was prepared by personnel of the Computational Mechanics Section of Lockheed's Huntsville Engineering Center. It constitutes final documentation of efforts performed under Contract NAS8-34507 for NASA-Marshall Space Flight Center.

The NASA-MSFC Contracting Officer's Representative for this research study was Dr. P.K. McConnaughey, ED32.

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1. INTRODUCTION

This report describes results of efforts by personnel of the Computational Mechanics Section at the Lockheed-Huntsville Engineering Center to assist the computational staff of NASA-MSFC in developing analytical capabilities for modeling hot gas flow on the fuel side of the SSME. The report specifically details work completed subsequent to the interim technical report submitted in August 1985 (Ref. 1). Computational and experimental results reported in Ref. 1 will not be reiterated here, and the reader is referred to that earlier document for those details.

Emphasis in this final report is placed on construction and documentation of a computational grid code for modeling an elliptical two-duct version of the Space Shuttle Main Engine (SSEM) fuel side hot gas manifold (HGM). Also computational results for flow past a support strut in an annular channel. These three-dimensional results constitute the initial phase of a more detailed study of flow through the SSME/HGM strut region being completed by Lockheed under contract NAS8-37359 (Ref. 2).

The approach for both of the aforementioned tasks is presented in Section 2. Sample results are contained in Section 3. Included in Appendixes A, B, and C are a brief input guide for the two-duct HGM code, a listing of the code input file, and a source listing of the grid code itself.

2. TECHNICAL APPROACH

2.1 GENERAL

The two-duct HGM grid generation uses as its fundamental building block the flexible algebraic techniques coded by the Lockheed Computational Mechanics Section into its own in-house geometry code. These techniques employ vector algebra, analytical geometry and transfinite interpolation to perform the computations in local curvilinear coordinates and generate the grid of discrete points in Cartesian coordinates. With this as a foundation, special subroutines were constructed for describing particular surface shapes for this complicated structure such as the hold in the bowl and the fairing for the transfer duct. The combination of these codings was assembled, debugged, streamlined, and well commented for use by NASA-MSFC computational engineers.

Early computational fluid dynamics results, reported in the interim report for this contract (Ref. 1) were performed with a finite difference code employing an explicit solution algorithm. Steady state was obtained from a trial initialization by performing successive iterations in time until all transients have involved away. The size of the time step used in this procedure is a strong function of the density of points in the grid. The higher the density, the smaller the allowable time step. For this reason, relatively coarse grids were used, even for regions near the solid walls.

Experience has dictated that much larger nodal densities near the walls are desirable for more accurate computational predictions. This precludes using an explicit code because of the unnecessarily large number of time steps required to obtain a steady state solution. The implicit code INS3D, developed at NASA-Ames (Ref. 3), was then chosen for additional SSME related computations. The implicit solution algorithm incorporated into this code allows for

much larger time steps even for grids of large nodal densities. The results reported in Section 3.2 were obtained with INS3D. A brief description of this code, and how it was applied, is contained in Section 2.3.

2.2 ELLIPTICAL TWO-DUCT MANIFOLD CODE

Nearly all computational codes which are available to numerically solve the three-dimensional fluid flow equations are designed to be applied to a well structured grid model of the flow region. To perform the calculations, generalized independent variables are introduced which transform the physical coordinates, (x, y, z), into general curvilinear coordinates, (η_1, η_2, η_3). Thus, the physical domain must be gridded as a single or series of hexahedral zones described by eight corner points, 12 edges, and six surfaces. Such an arbitrary zone is shown in Fig. 2-1.

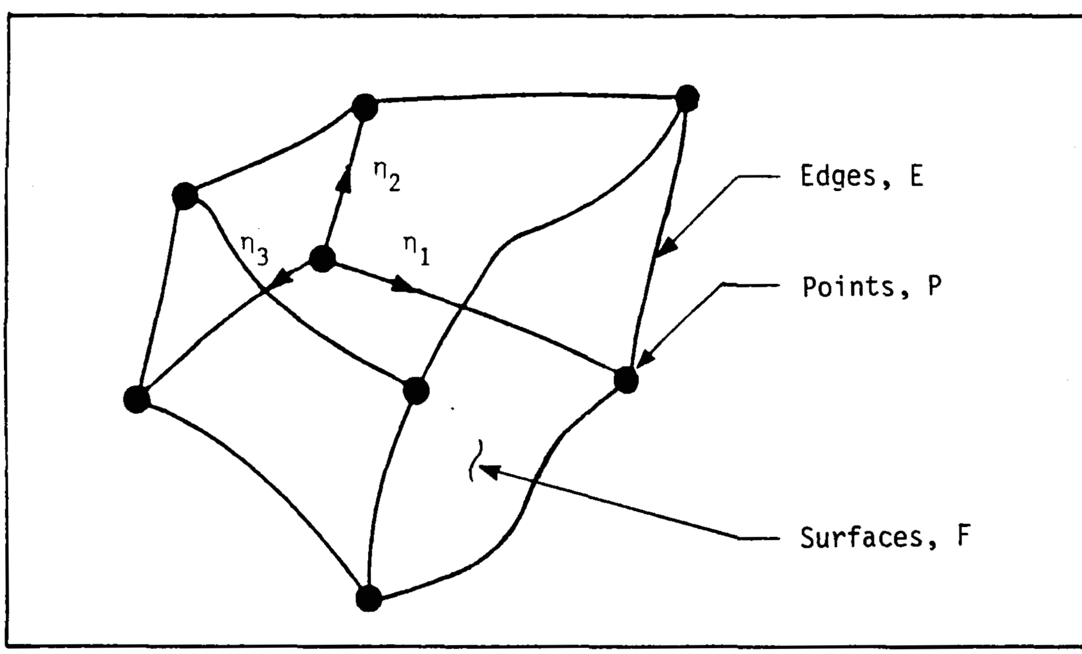

Fig. 2-1 Hexahedral Element Showing Local Intrinsic Coordinates

The approach used in the current study was to provide an algebraic grid generation code which would produce the Cartesian coordinates (x, y, z), for points along the lines of constant (η_1, η_2, η_3). Basic mathematical techniques taken from analytic geometry and vector algebra were employed to describe a hexahedral zone in terms of piecewise continuous analytic functions which represent the zonal edges and surfaces.

An intrinsic curvilinear coordinate system can be produced by mapping a unit cube onto the simply connected hexahedral zone. What is needed is a transformation function that will map a unit cube in (η_1, η_2, η_3) space univalently onto the hexahedral volume of interest thus producing the required intrinsic coordinate system. A procedure which produces the desired result is referred to as either the method of transfinite interpolation of multivariate blending function interpolation (Ref. 1). A brief description of this method follows.

Let $F(\eta_1, \eta_2, \eta_3)$ be a vector-valued functional representing the region R of interest in curvilinear space. Then as (η_1, η_2, η_3) range over R, F traces out the region in Euclidean space (x, y, z). Also let ϕ, ψ, and λ be blending functions which obey the cardinality conditions:

$$\phi_i(\eta_1 = l) = \begin{cases} 1 \text{ if } i = l \\ 0 \text{ if } i \neq l \end{cases}$$

$$\psi_j(\eta_2 = m) = \begin{cases} 1 \text{ if } j = m \\ 0 \text{ if } j \neq m \end{cases}$$

$$\lambda_k(\eta_3 = n) = \begin{cases} 1 \text{ if } k = n \\ 0 \text{ if } k \neq n \end{cases}$$

The simplest form of blending functions meeting these conditions are

$$\phi_o(\eta_1) = 1 - \eta_1 \qquad \phi_1(\eta_1) = \eta_1$$
$$\psi_o(\eta_2) = 1 - \eta_2 \qquad \psi_1(\eta_2) = \eta_2$$
$$\lambda_o(\eta_3) = 1 - \eta_3 \qquad \lambda_1(\eta_3) = \eta_3$$

Then a trilinearly blended interpolant of F, which will map a unit cube onto the region R is given by

$$U(\eta_1,\eta_2,\eta_3) = \begin{bmatrix} x(\eta_1,\eta_2,\eta_3) \\ y(\eta_1,\eta_2,\eta_3) \\ z(\eta_1,\eta_2,\eta_3) \end{bmatrix}$$

$$= (1-\eta_1)F(0\ \eta_2,\eta_3) + \eta_1 F(1,\eta_2,\eta_3)$$

$$+ (1-\eta_2)F(\eta_1,0,\eta_3) + \eta_2 F(\eta_1,1,\eta_3)$$

$$+ (1-\eta_3)F(\eta_1,\eta_2,0) + \eta_3 F(\eta_1,\eta_2,1)$$

$$- (1-\eta_1)(1-\eta_2))F(0,0,\eta_3) - (1-\eta_1)\eta_2 F(0,1,\eta_3)$$

$$- \eta_1(1-\eta_2)F(1,0,\eta_3) - \eta_1\eta_2 F(1,1,\eta_3)$$

$$- (1-\eta_1)\eta_3 F(0,\eta_2,0) - (1-\eta_1)\eta_3 F(0,\eta_2,1)$$

$$- \eta_1(1-\eta_3)F(1,\eta_2,0) - \eta_1\eta_3 F(1,\eta_2,1)$$

$$- (1-\eta_2)(1-\eta_3)F(\eta_1,0,0) - (1-\eta_2)\eta_3 F(\eta_1 0,1)$$

$$- \eta_2(1-\eta_3)F(\eta_1,1,0) - \eta_2\eta_3 F(\eta_1,1,1)$$

$$+ (1-\eta_1)(1-\eta_2)(1-\eta_3)F(0,0,0) + (1-\eta_1)(1-\eta_2)\eta_3 F(0,0,1)$$

$$+ (1-\eta_1)\eta_2(1-\eta_3)F(0,1,0) + (1-\eta_1)\eta_2\eta_3 F(0,1,1)$$

$$+ \eta_1(1-\eta_2)(1-\eta_3)F(1,0,0) + \eta_1(1-\eta_2)\eta_3 F(1,0,1)$$

$$+ \eta_1\eta_2(1-\eta_3)F(1,1,0) + \eta_1\eta_2\eta_3 F(1,1,1)$$

where

$F(0,\eta_2,\eta_3)$ represents a surface with $\eta_1=0$, etc.
$F(0,0,\eta_3)$ represents an edge with $\eta_1=\eta_2=0$, etc.
$F(0,0,0)$ represents a point with $\eta_1=\eta_2=\eta_3=0$, etc.

In two dimensions this equation performs a bilinear interpolation over an arbitrary region consisting of four distinct corners simply connected by four edges, where

$F(0,\eta_2) = [{x \atop y}]$ along $EDGE_4$ $\qquad F(0,0) = [{x \atop y}]$ at $POINT_1$

$F(1,\eta_2) = [{x \atop y}]$ along $EDGE_2$ $\qquad F(0,1) = [{x \atop y}]$ at $POINT_4$

$F(\eta_1,0) = [{x \atop y}]$ along $EDGE_1$ $\qquad F(1,0) = [{x \atop y}]$ at $POINT_2$

$F(\eta_1,1) = [{x \atop y}]$ along $EDGE_3$ $\qquad F(1,1) = [{x \atop y}]$ at $POINT_3$

and the interpolation equation for F could be rewritten as

$$U = [{x \atop y}] = (1-\eta_1)EDGE_4 + \eta_1 EDGE_2 + (1-\eta_2)EDGE_1 + \eta_2 EDGE_3$$

$$- (1-\eta_1)(1-\eta_2)POINT_1 - (1-\eta_1)\eta_2 POINT_4$$

$$- \eta_1(1-\eta_2)POINT_2 - \eta_1\eta_2 POINT_3$$

In this equation $EDGE_4$ represents a vector-valued functional along edge four, etc. Examination of this equation shows that it performs linear interpolations between $EDGE_1$ and $EDGE_3$ and between $EDGE_2$ and $EDGE_4$, hence the term bilinear interpolation. Hence, if the functional for each edge can be derived and is analytic, a grid or mesh of node points can be generated by substituting values of η_1 and η_2 into the equation.

In three dimensions the general equation above performs trilinearly blended interpolation over an arbitrary region consisting of eight distinct corner points simply connected by 12 edges, where

$$F(0,\eta_2,\eta_3) = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \text{ on } \mathrm{SIDE}_5, \text{ etc.}$$

$$F(0,0,\eta_3) = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \text{ along } \mathrm{EDGE}_5, \text{ etc.}$$

$$F(0,0,0) = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \text{ at } \mathrm{POINT}_1, \text{ etc.}$$

and which can be rewritten as

$$\begin{aligned}
U &= \begin{bmatrix} x \\ y \\ z \end{bmatrix} \\
&= (1-\eta_1)\mathrm{SIDE}_5 + \eta_1\mathrm{SIDE}_6 + (1-\eta_2)\mathrm{SIDE}_2 + \eta_2\mathrm{SIDE}_4 + (1-\eta_3)\mathrm{SIDE}_1 + \eta_3\mathrm{SIDE}_3 \\
&\quad - (1-\eta_1)(1-\eta_2)\mathrm{EDGE}_5 - (1-\eta_1)\eta_2\mathrm{EDGE}_8 - \eta_1(1-\eta_2)\mathrm{EDGE}_6 - \eta_1\eta_2\mathrm{EDGE}_7 \\
&\quad - (1-\eta_1)(1-\eta_3)\mathrm{EDGE}_4 - (1-\eta_1)\eta_3\mathrm{EDGE}_{12} - \eta_1(1-\eta_3)\mathrm{EDGE}_2 - \eta_1\eta_3\mathrm{EDGE}_{10} \\
&\quad - (1-\eta_1)(1-\eta_3)\mathrm{EDGE}_1 - (1-\eta_2)\eta_3\mathrm{EDGE}_9 - \eta_2(1-\eta_3)\mathrm{EDGE}_3 - \eta_2\eta_3\mathrm{EDGE}_{11} \\
&\quad + (1-\eta_1)(1-\eta_2)(1-\eta_3)\mathrm{POINT}_1 + (1-\eta_1)(1-\eta_2)\eta_3\mathrm{POINT}_5 + (1-\eta_1)\eta_2(1-\eta_3)\mathrm{POINT}_4 \\
&\quad + (1-\eta_1)\eta_2\eta_3\mathrm{POINT}_8 + \eta_1(1-\eta_2)(1-\eta_3)\mathrm{POINT}_2 + \eta_1(1-\eta_2)\eta_3\mathrm{POINT}_6) \\
&\quad + \eta_1\eta_2(1-\eta_3)\mathrm{POINT}_3 + \eta_1\eta_2\eta_3\mathrm{POINT}_7
\end{aligned}$$

where SIDE_i, EDGE_j, POINT_k represent vector-valued functionals on the surfaces, along the edges, and at the corner points, respectively.

This equation reduces to the previous two-dimensional analog along any flat surface or along any surface in which a straight line can be drawn between any two opposing edges such that the line lies entirely within the surface.

With the general transformation, any point in local coordinates η_1, η_2, η_3 can be related to the physical Cartesian coordinates x, y, z. The entire grid of discrete points is generated in the HGM code using this concept. This general interpolant can accommodate any stretching function for concentrating points near walls or regions of large gradients. Furthermore, the edges of the hexahedral can be segmented allowing another means of grid spacing control.

2.3 STRUT IN ANNULUS

Previous SSME/HGM computations reported earlier by Lockheed (Refs. 1 and 4) and other investigations (Ref. 5) have either not modeled the support strut region in the manifold or poorly approximated its influence on the flowfield environment. It was for this reason that NASA requested an additional computations be made which accurately included these obstacles in the flow path at the entrance to the fuel bowl of the manifold. Initial work on this task was performed under this contract and is being reported here. Results of follow-on work are presented in the final report for NAS8-37359 (Ref. 2).

The approach was to generate a computational grid consisting of a single strut in an annular channel with the dimensions of the strut size, channel width, and channel curvature being approximately the same as those in the actual SSME/HGM. Numerical experiments were then to be performed using a three-dimensional incompressible Navier-Stokes code which employed an implicit solution algorithm. The Lockheed in-house algebraic grid code was used to model the geometry and INS3D was used to obtain flowfield solutions.

The INS3D code solves the three-dimensional incompressible Navier-Stokes equations in primitive variables. An implicit finite difference operator is used in a general curvilinear coordinate system. The solution procedure uses the standard approximate factorization scheme. The pressure field solution is based on the concept of adding a time-like pressure term into the continuity equation via an artificial compressibility factor. This approach was first introduced by Chorin (Ref. 6) and later adopted by Steger and Kutler (Ref. 7) using an implicit approximate factorization scheme by Beam and Warming (Ref. 8). It is from these earlier developments that INS3D evolved (Ref. 3).

Values of the artificial compressibility factor are bounded in order not to influence the steady state mass conservation. In the INS3D methodology mass conservation is of crucial importance if a stable solution is to result. Since the continuity equation is modified to obtain a hyperbolic-type equation, pressure waves of finite speed will be introduced. The speed of propagation of these pressure waves depends on the magnitude of the compressibility parameter. When the pressure waves travel through a given location a pressure gradient is created there. Near boundaries, the viscous boundary layer must respond to this pressure fluctuation. To accelerate convergence and avoid slow fluctuations it is desirable that the time required for pressure waves to propagate through the region of interest be much less than the time needed for the boundary layer to fully adjust itself. This condition provides for a lower bound on the artificial compressibility factor. The upper bound on this factor comes not from the physics but from the effects of the approximate factorization of the governing equations. When the finite difference form of the equation is factored, higher order cross-differencing terms are added to the left-hand side of the equation. These added terms must be made smaller than the original terms everywhere in the computational domain. This condition results in an upper bound on the compressibility factor.

It is well know in the computational fluid dynamics community that the approximate factorization schemes which employ alternating direction type implicit methods have stability problems in three dimensions (Refs. 9 through 12). The INS3D code satisfactorily overcomes this difficulty by providing second and fourth order smoothing terms to the algorithm to ensure stability without adversely affecting mass conservation.

Currently, the Computational Mechanics Section at Lockheed-Huntsville has the INS3D code operational on the Cray-XMP at NASA-MSFC and NASA-Ames as well as on its own VAX 11/785.

3. RESULTS

3.1 MANIFOLD GRID CODE

3.1.1 Geometry and Grid

A schematic representation showing the construction of the geometry which has been modeled is presented in Fig. 3-1. Only the outer wall is displayed and two perspectives are shown. These solid surface plots were generated with the actual output from the grid code. Only half of the manifold is represented since, due to the plane of symmetry which divides the two transfer ducts, only half need be computationally modeled.

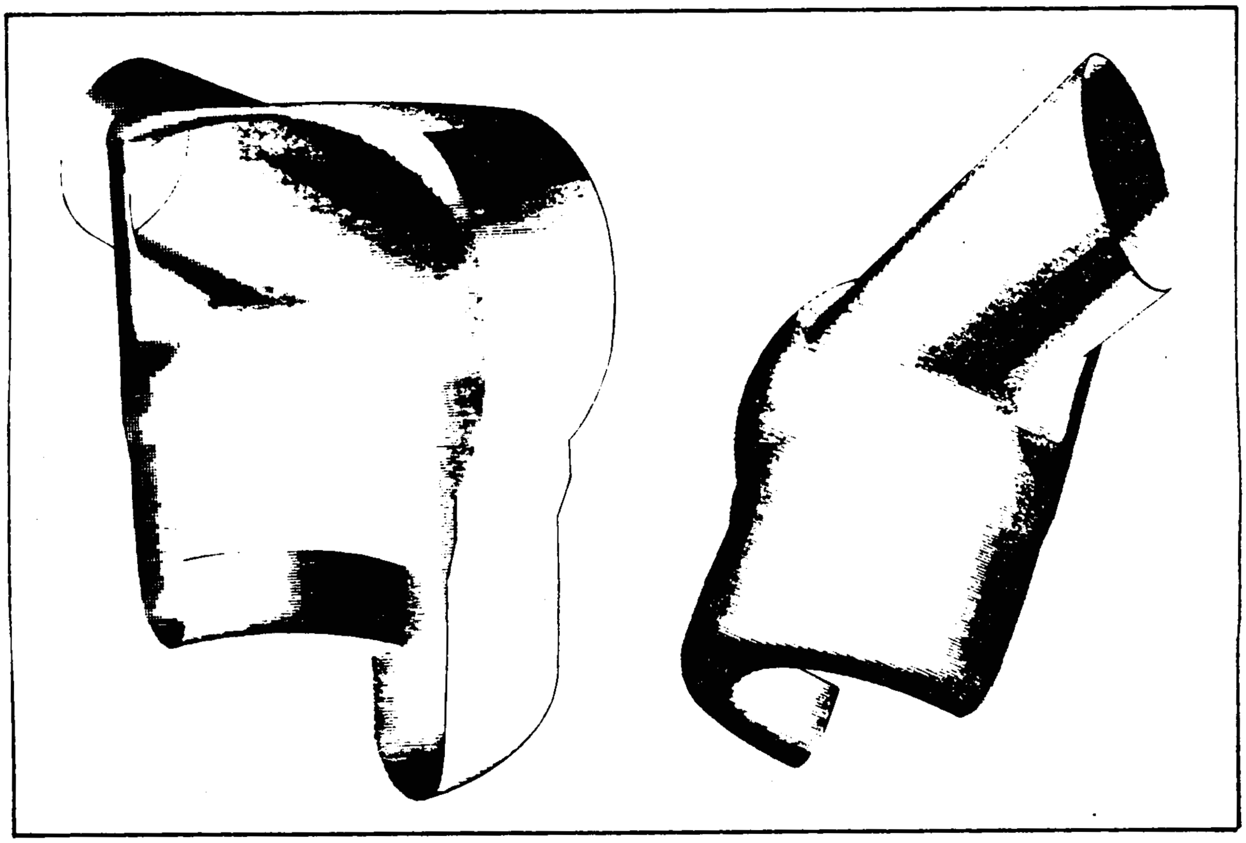

Fig. 3-1 Schematic Showing Outer Wall of HGM Geometry that has been Modeled

The geometry is generated in five separate pieces or zones. The five zones are shown in Figs. 3-2 and 3-3. Each zone has a general hexahedral shape, and in these figures all of the eight corner points of each are clearly indicated. Figure 3-4 shows the Cartesian coordinate system relative to which the position of each node in the grid is referenced. Except for the hole perimeters in the outer wall of Zone 2 and the fairing at the entrances to Zone 3, the edges of each zone can be described as piecewise continuous segments composed of either straight lines, circular arcs, or elliptical arcs. In addition, excluding the two special regions previously mentioned, the surfaces of each zone can be generated by rotating an edge about an appropriate axis. For Zones 1, 2, 4, and 5, the X axis is the axis of revolution.

Zones 1 and 2 make up the bowl section of the manifold and contain 58 nodes in the x-direction, from bowl entrance to rear of the bowl, 109 nodes in the circumferential direction and 21 nodes between the inner and outer surfaces. Distribution of nodes in the bowl is presented in Fig. 3-5.

Zones 4 and 5, the turnaround duct (TAD), are composed of 71 nodes in the streamwise direction, 109 nodes in the circumferential direction (0 to 180 deg), and 21 nodes across the duct between inner and outer surfaces. Two perspectives showing this nodal distribution are shown in Fig. 3-6.

Zone 3 is the elliptical transfer duct portion. This duct has been generated with 59 nodes along the duct axis and 44 x 30 nodes in a cross section. Surface and cross-section grids for this zone are given in Fig. 3-7. Figure 3-8 displays a view of the manifold outer wall grid to show grid continuity from one zone to another. To summarize, each zone contains the following number of nodal points:

• Zones 1 and 2 (Bowl):	132,762
• Zones 3 (Transfer Duct):	77,880
• Zones 4 and 5 (TAD):	162,519
• Manifold total Nodes:	373,161

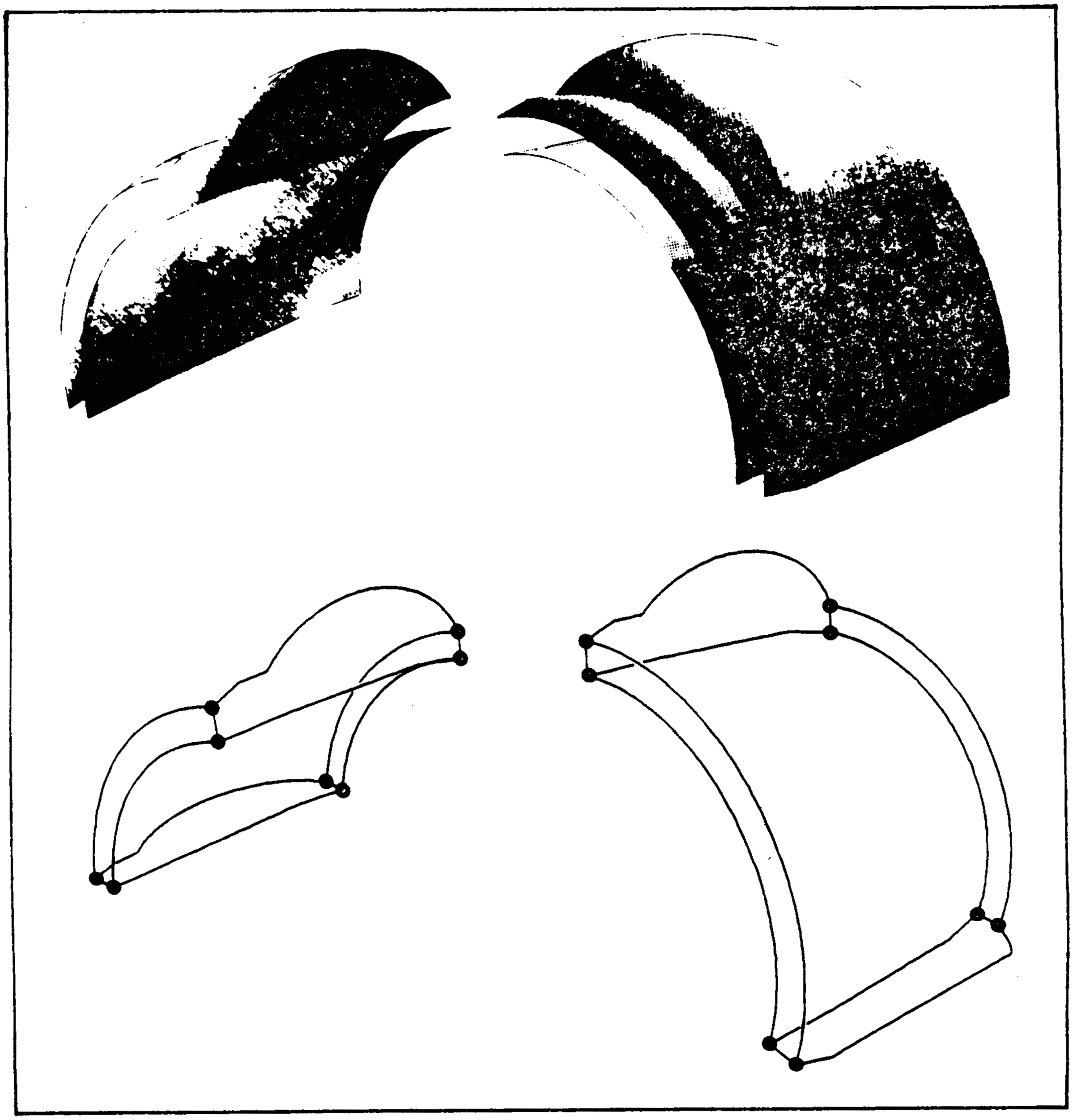

Fig. 3-2 Schematic Showing First Two Zones (Zone 1 Left; Zone 2, Right) into Which the Two-Duct HGM was Subdivided

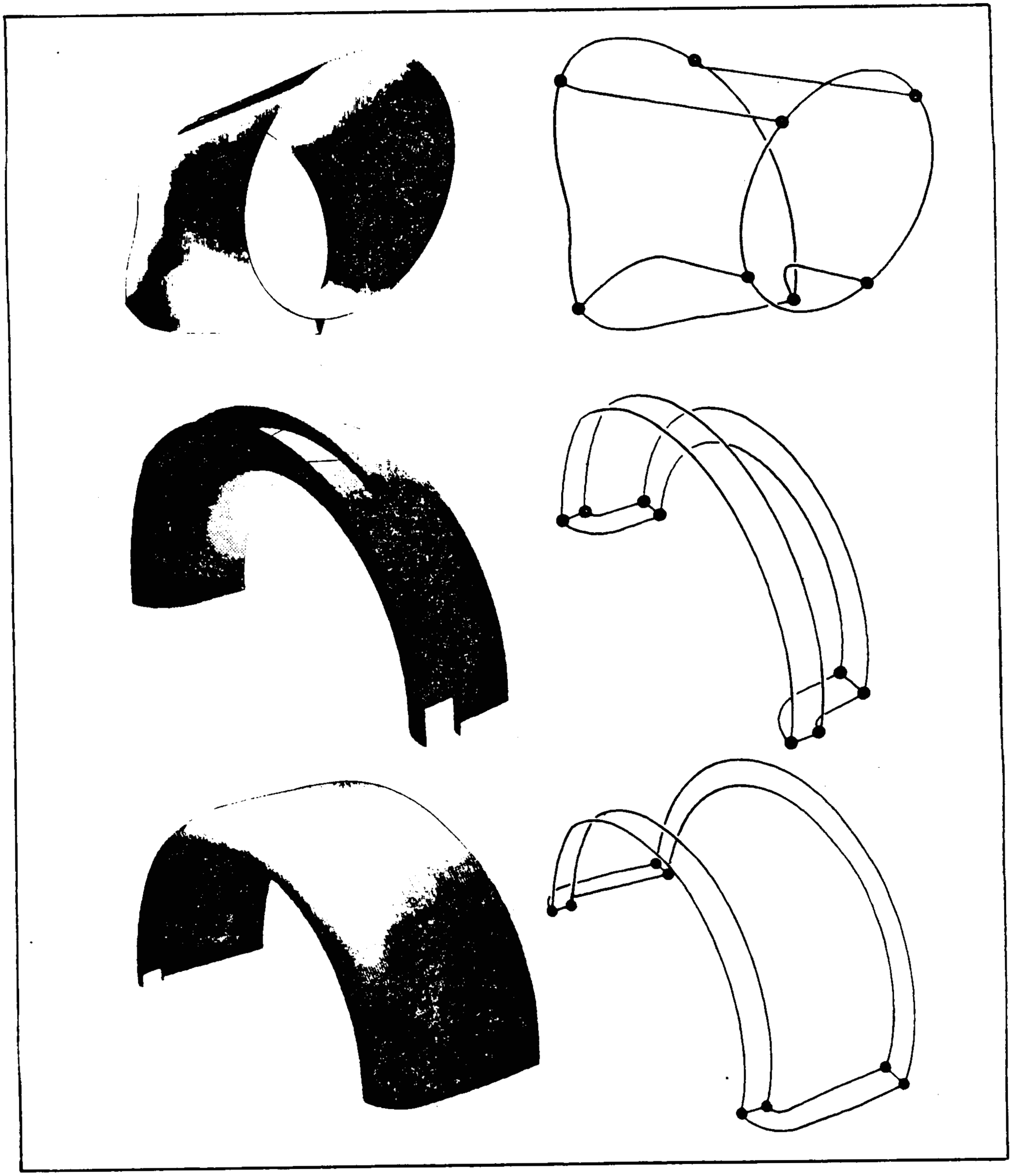

Fig. 3-3 Schematic Showing Zones 3, Top, and 4, Middle, and 5 of the Two-Duct HGM Model

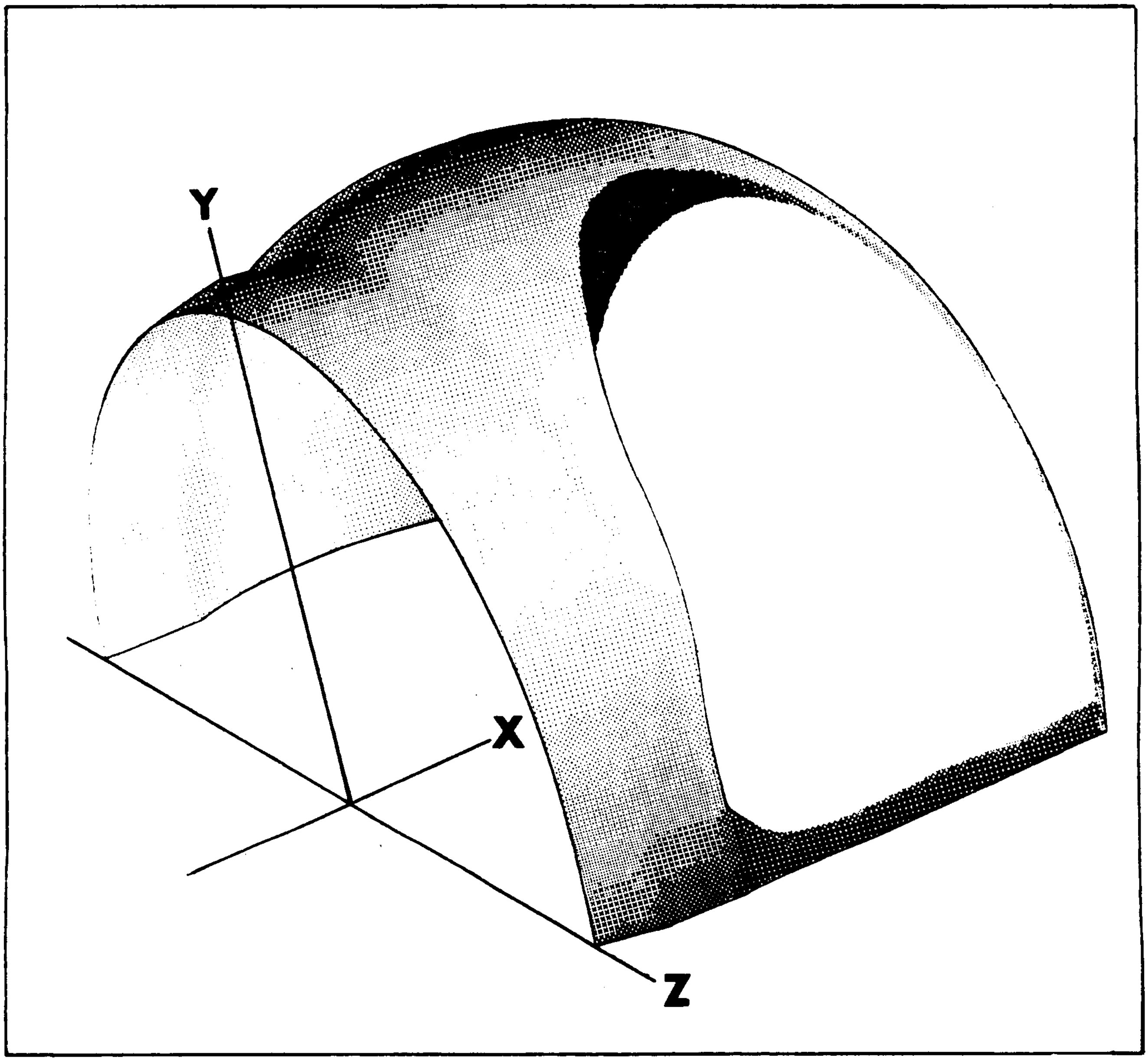

Fig. 3-4 Cartesian Coordinate System Relative to Which Positions of All Nodes are Referred

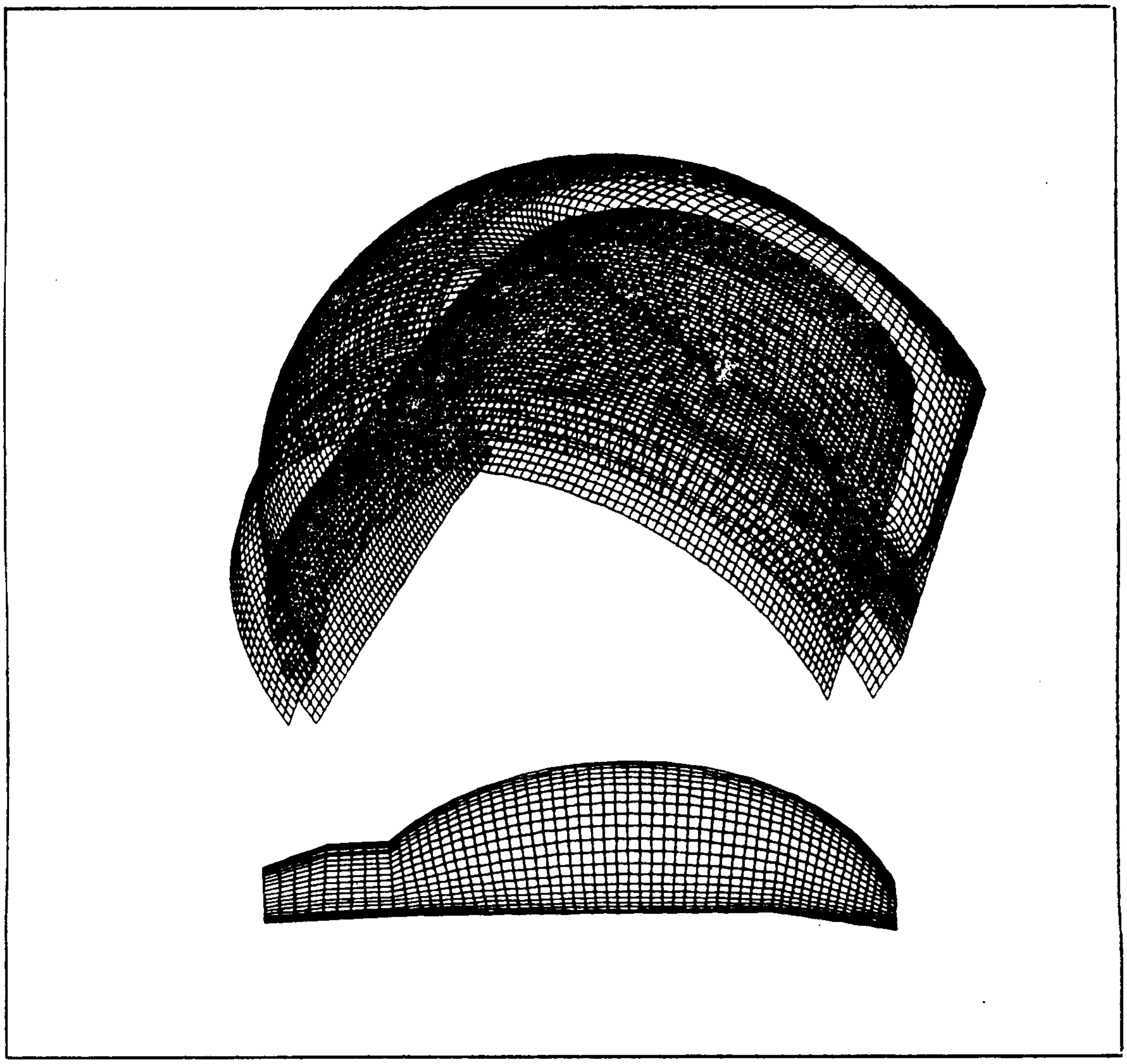

Fig. 3-5 Grid Plots for Inner and Outer Surfaces of Zones 1 and 2 as Well as Internal Grid at the Common Place of Intersection

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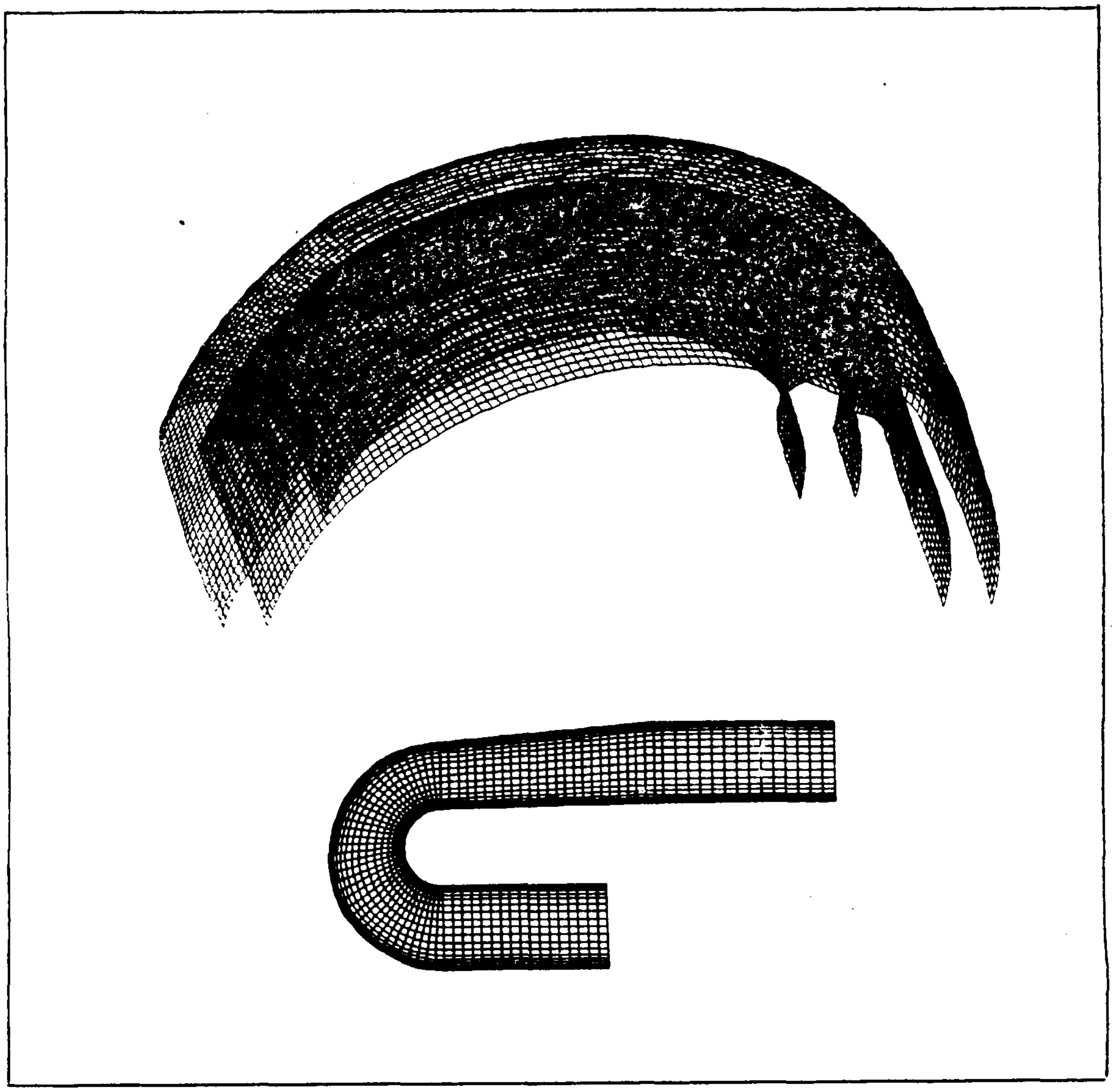

Fig. 3-6 Grid Plots of TAD Internal Grid (Bottom) and Grid Distribution on Inner and Outer Surfaces

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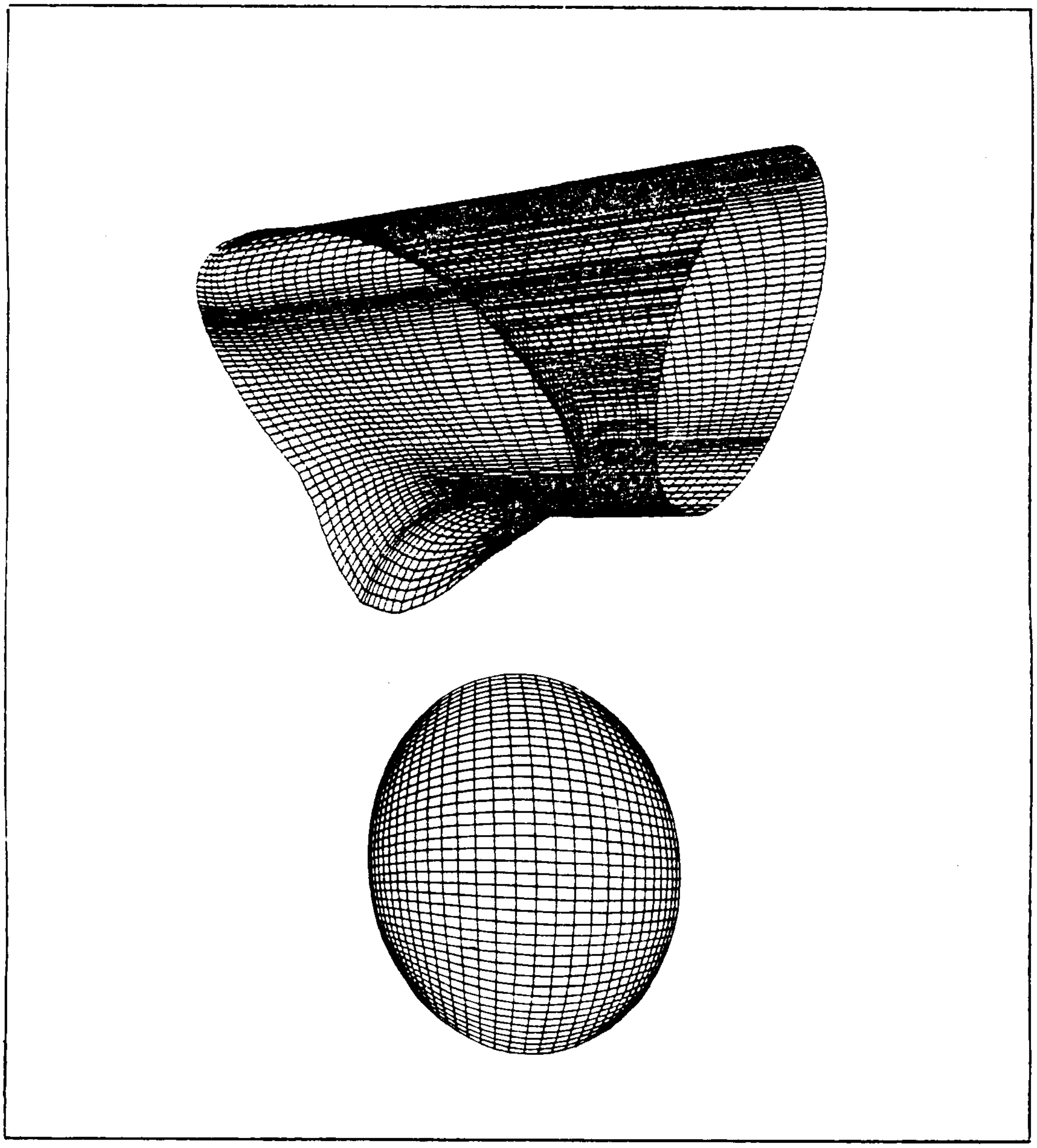

Fig. 3-7 Surface and Cross-Section Node Distribution for Transfer Duct

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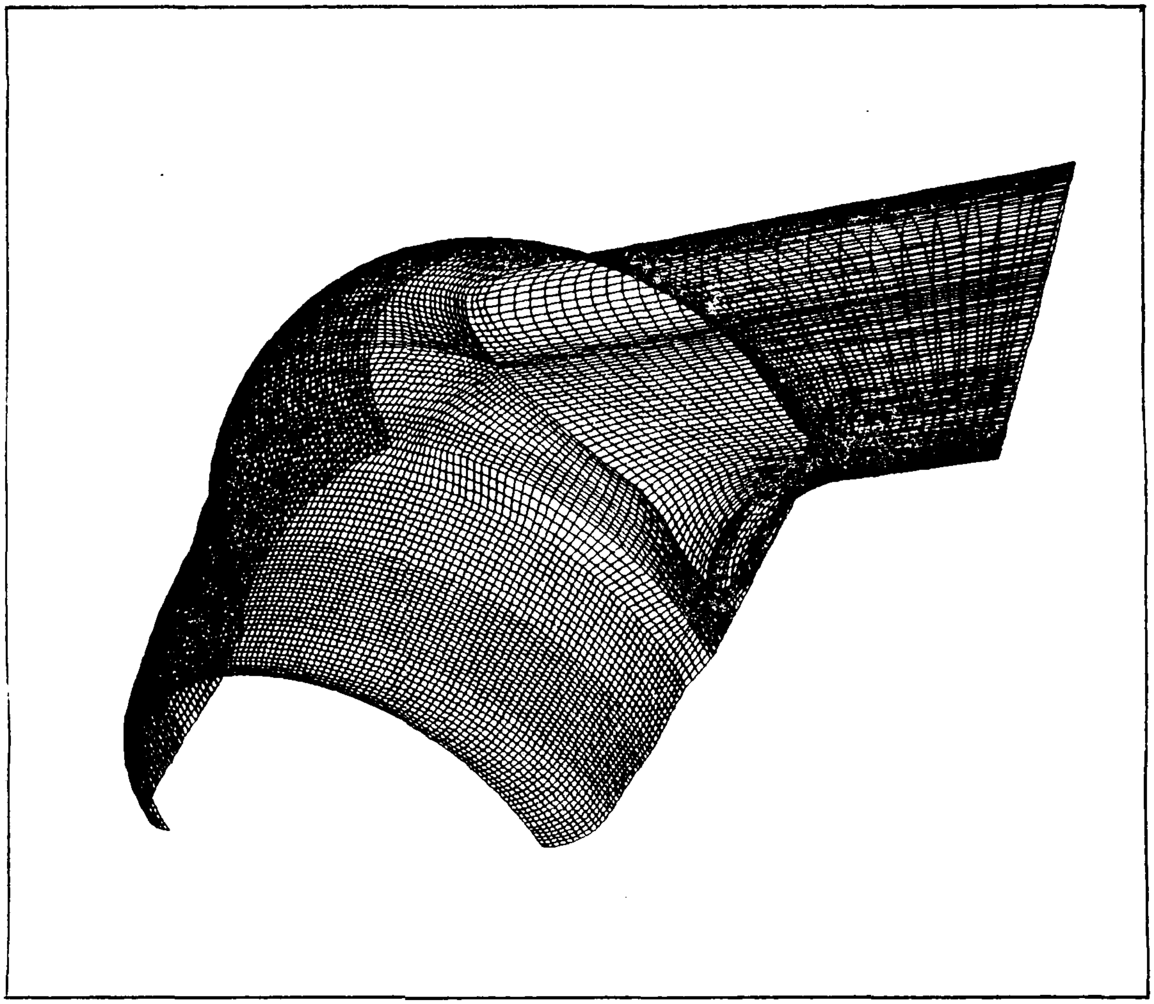

Fig. 3-8 Grid Plot Showing Node Distribution on Outer Wall of Zones 1, 2, and 3 Displaying Continuity of Grid Lines from One Zone to Another

The internal grid resolution presented in the previous figures is adequate for a laminar viscous computation but would need to be modified for application to a turbulent computation. The procedure for doing this will be described in Section 3.1.4.

3.1.2 Computer Code

A concise input guide and an input listing for the grids displayed in Figs. 3-4 through 3-8 is also included in Appendixes A and B, respectively. A source listing of the two-duct HGM geometry code is provided in Appendix C.

Figure 3-9 shows the primary calling sequence. For completeness, secondary calling sequences are given in Fig. 3-10. A brief explanation of the function of the major subroutines in the primary calling sequence follows:

- INITIAL Reads the first two lines of the input file, initializes coefficient arrays, and defines logical unit numbers and counters.
- INPUT Reads the remainder of the input file and sets all parameters to be used in remaining subroutines.
- MESH The controlling subroutine for the generation of the spatial coordinates of each node in each zone.
- ETABC Calculates the values of η_1, η_2, η_3 along the I, J, and K directions for each hexahedral shaped section of each zone.
- EDGES Determines the Cartesian coordinates for nodes along each edge of each side of each section of each zone using the bilinear/trilinear interpolation scheme.
- SURFACE Determines the Cartesian coordinates of nodes on a three-dimensional surface using the trilinear interpolation scheme. Here, all outer and internal surface nodes are calculated from the previously determined edge distributions.
- OUTPUT Provides printed output and stores geometry in File 20 for use in plotting or as input to an integration code.

The output to File 20 is in the format to be input as a multi-grid geometry file to the PLOT3D plotting code.

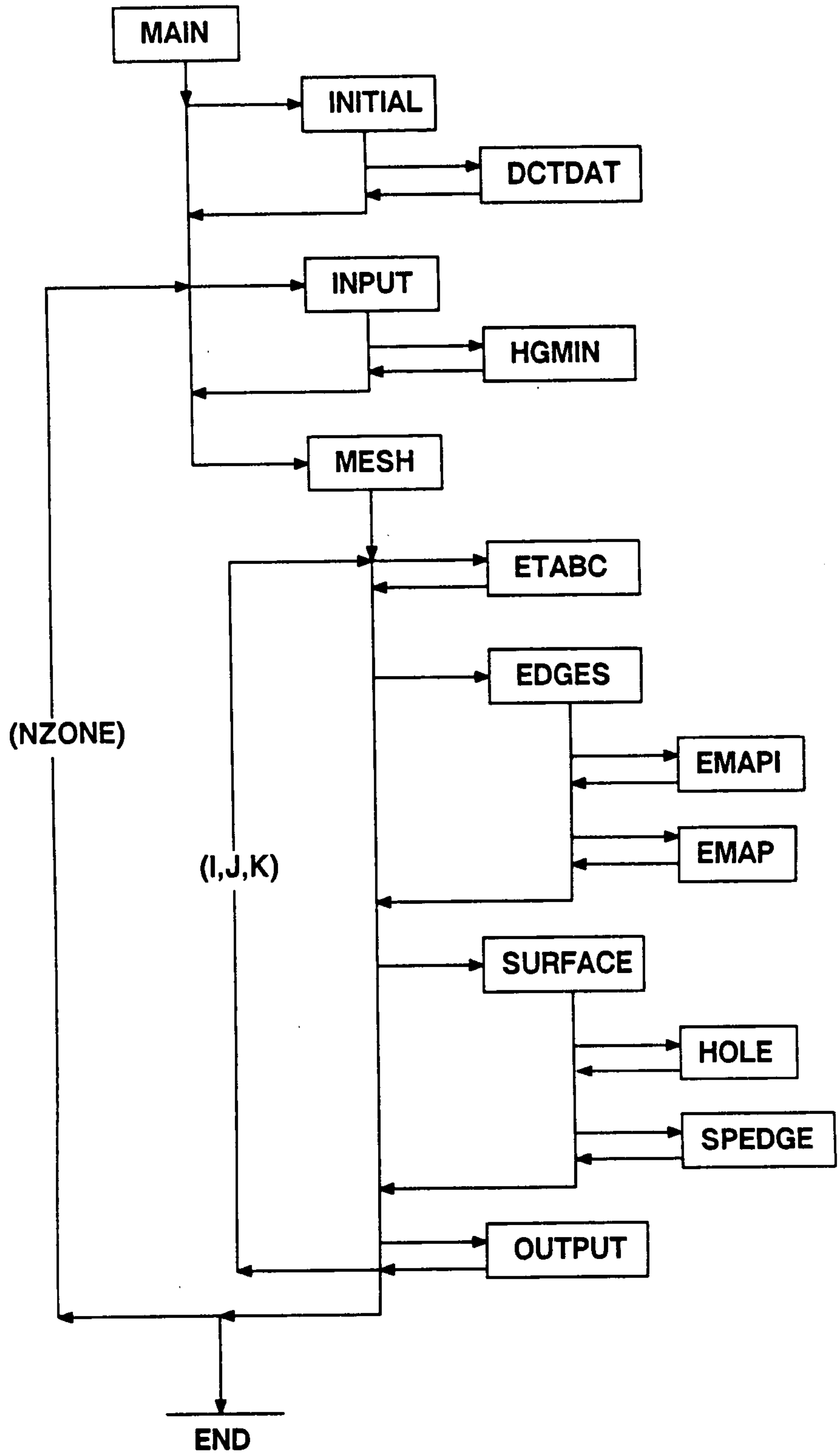

Fig. 3-9 Primary Calling Sequence for Two-Duct HGM Grid Code

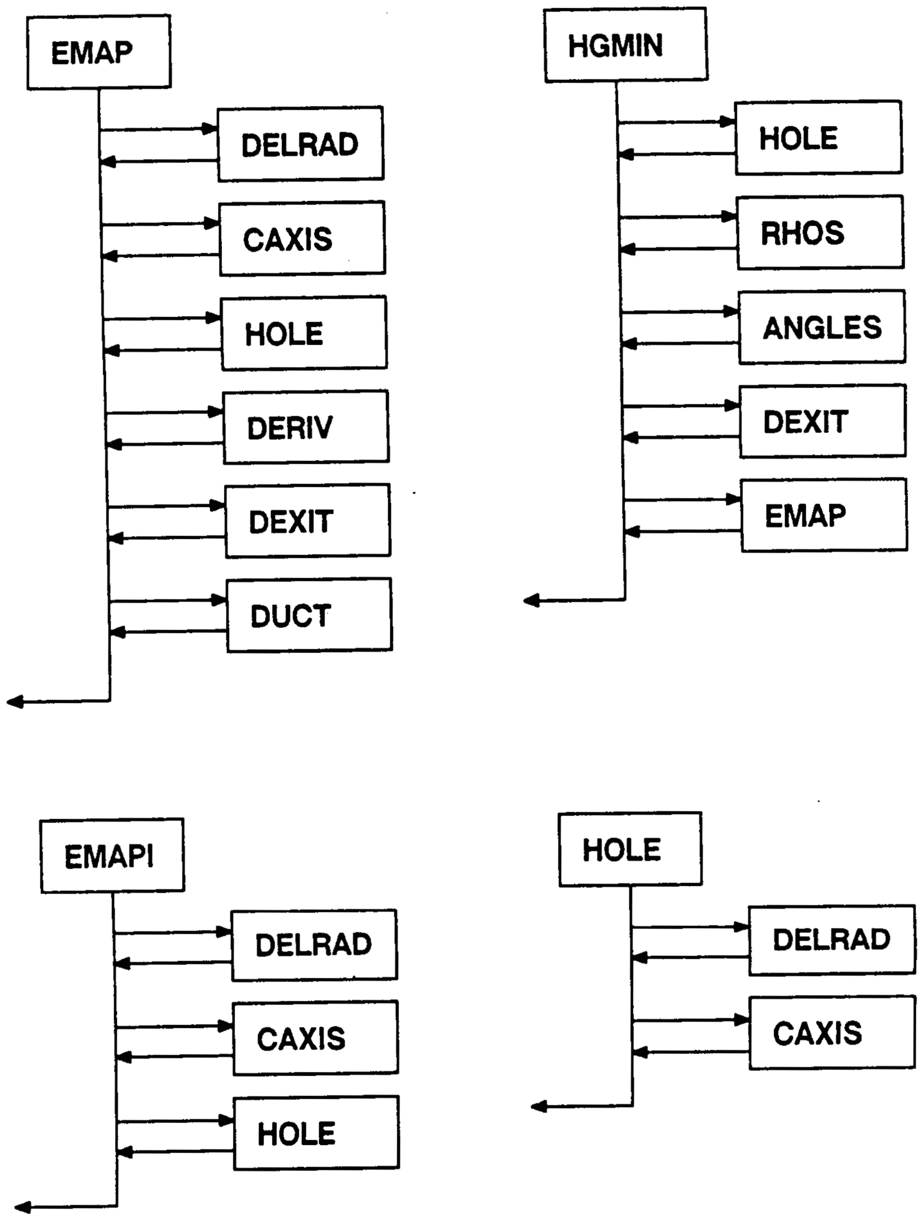

Fig. 3-10 Secondary Calling Sequences for Two-Duct HGM Grid Code

The grid code is written in standard FORTRAN. However, the listing provided in Appendix C is a VAX 11/785 version and could contain some generic VAX statements which would have to be translated if used on a different machine.

3.1.3 Code Implementation

To implement the HGM geometry code as it appears in the listing of Appendix C, the input listing of Appendix B must correspond to logical Unit 5. Unit 6 must be assigned to the written output and Unit 20 to the geometry file which will contain the x, y, z coordinates for each node in each zone.

The input file is labeled on the card image which begins each zone input to indicate the zone being described by the succeeding card images. These zone labels correspond to those shown in Figs. 3-2 and 3-3. The input file, as listed in Appendix B, will create a multi-grid file containing all five zones. Using this input is, of course, possible only if run on a computer with sufficient CPU and/or disk storage. Alternatively the bowl, transfer duct, and TAD can be run separately by changing the second parameter on card image two, of the input, from a 6 to a 1, 3, and 4, respectively.

A detailed description of the input file to the code is provided in Appendix A. Modifications to the geometry can be facilitated by studying the input guide while observing both the input file and the detailed grid pictures presented in Figs. 3-3 through 3-8. Redistributions of nodes can be accomplished by making minor modifications to the input files. For example, for a turbulent computation if the nodes in Zone 4 near the wall require redistribution closer to the wall then a change would need to be made to card type 9 on the last line of the input for that zone. The 6.0 appearing in the η_2 position could be changed to 10.0 (see page A-10).

Dimensioning in the program has been kept to a minimum. The largest dimensioned array in the bulk of the code is NODENUM(5000). At the very end of all computations the PLOT3D file can be generated by employing the program in Appendix D.

In this subroutine the x, y, z coordinate arrays are each dimensioned to 200,000. The 5,000 corresponds to twice the maximum number of nodes in a plane perpendicular to the marching direction (η direction input on card 7) for creating the geometry. The 200,000 must be equal to or greater than the number of nodes in the largest zone, which is zone 5, the second half of the TAD. In Zones 1, 2, 4, and 5, the direction of η_1 is from TAD entrance to bowl back wall; the η_2 direction is from inner to outer wall; and η_3 is directed from side opposite transfer duct circumferentially. In zone 3, η_2 increases in the streamwise direction from bowl outward, and $\eta_1 \times \eta_3$ form the cross planes in the duct.

Note that the code is designed to output each zone of the manifold so that each has one cross plane in common with the preceding zone(s). This must be remembered for incorporating the grid into a flowfield solver code. The geometry must be integrated in a multi-block or multi-zone fashion. If the computer available has large enough core memory or if it is a large virtual machine then Zones 1 and 2, and 4 and 5 can easily be combined into two larger zones since at all common planes the nodal positions match exactly. It is not recommended that zones 1, 2, 4, and 5 be combined into one zone. This could easily be accomplished, since continuity in all three η directions would be maintained, but the total number of nodes would be untenable on all but a Cray II or an ETA 10 machine.

3.2 STRUT LAMINAR COMPUTATION

The Lockheed-Huntsville algebraic computational grid generation code was employed to generate a model for a single support strut in an annular channel. A C-type grid was selected for nodal distribution in parallel annular surfaces and is shown in Fig. 3-11. This is a 26 x 201 node structure with stretching toward the strut surface. The three-dimensional model consisted of 31 such surfaces in concentric cylindrical fashion with stretching toward inner and outer surfaces. Figure 3-11 also shows part of the solid surfaces in the model. The total number of grid points in the computational domain was 162,006.

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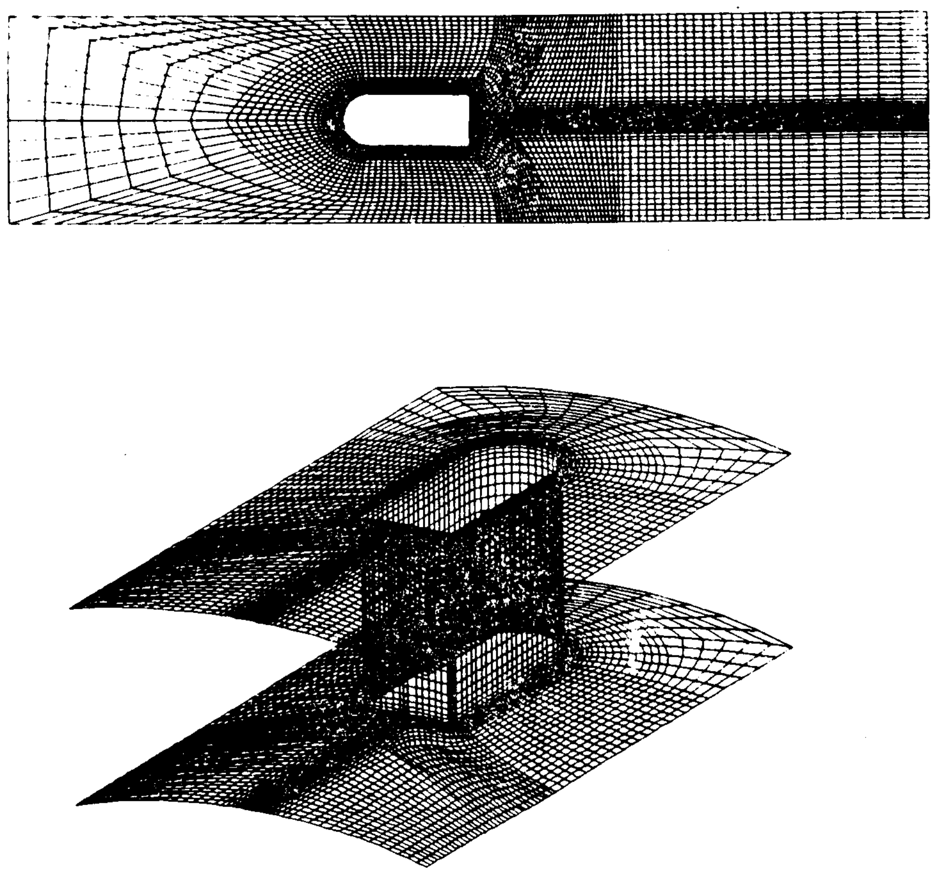


Fig. 3-11 Grid Plots Showing C-Grid Used in Each of the 31 Circumferential Planes (Top) and Partial Surface Grids of Strut and Inner Outer Wall

The basic INS3D code was modified for treating the sides of the computational domain as periodic boundaries and for special treatment of the common grid plane at the center of the grid behind the strut. At the entrance plane, the velocity components were initialized for fully developed laminar channel flow at zero degree incidence to the strut. Velocity and pressure were then held fixed throughout the computation. A nondimensional time step of 0.025 was used and a steady solution for Reynolds number of 500 was obtained in 800 iterations. Figures 3-12 to 3-21 present various characteristics of this steady laminar solution. Velocity magnitude contours and static pressure contours in the region surrounding the strut in concentric cylindrical surfaces near the inner wall, center of annulus, and near outer wall are shown in Figs. 3-12, 3-13, and 3-14, respectively. An expanded view of the same information for the central annular surface appears in Fig. 3-15. The velocity contours in the figure clearly shows the extension of the strut wake region several strut lengths downstream. In the SSME/HGM the support struts are at the entrance to the bowl (exit of the TAD). Even though these current results are laminar and steady, the influence of the strut wake is shown to be significant and could cause a significant difference in the predicted flow through the transfer ducts.

More details of the strut near wake region for a central circumferential surface and central radial surface are given in Figs. 3-16 and 3.17. The influence of the wake flow pattern on flow particles originating upstream of the wake is indicated by the particle traces shown in Fig. 3-18. To further illustrate the three-dimensional character of this region of the wake Fig. 3-19 and 3-20 trace particle paths beginning at positions in the wake itself. Clearly, if the wake were unsteady, as it is in the actual HGM, these complicated flow patterns will move into the bowl, interact, and exit through the transfer ducts.

For completeness, surface pressure distribution on the strut itself is presented in Fig. 3-21.

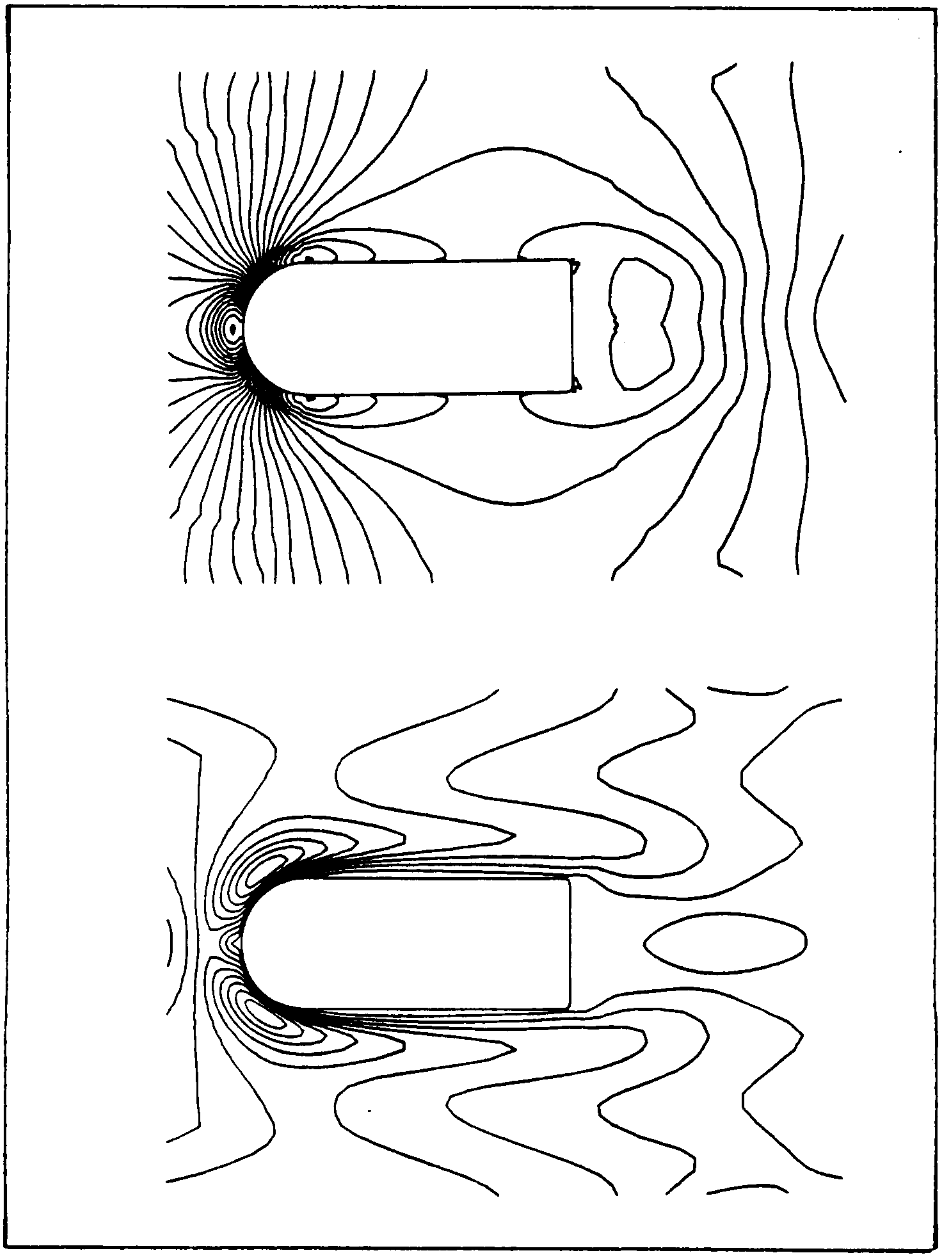


Fig. 3-12 Static Pressure Contours (Top) and Velocity Magnitude Contours for Strut in Annular Channel near Inner Wall

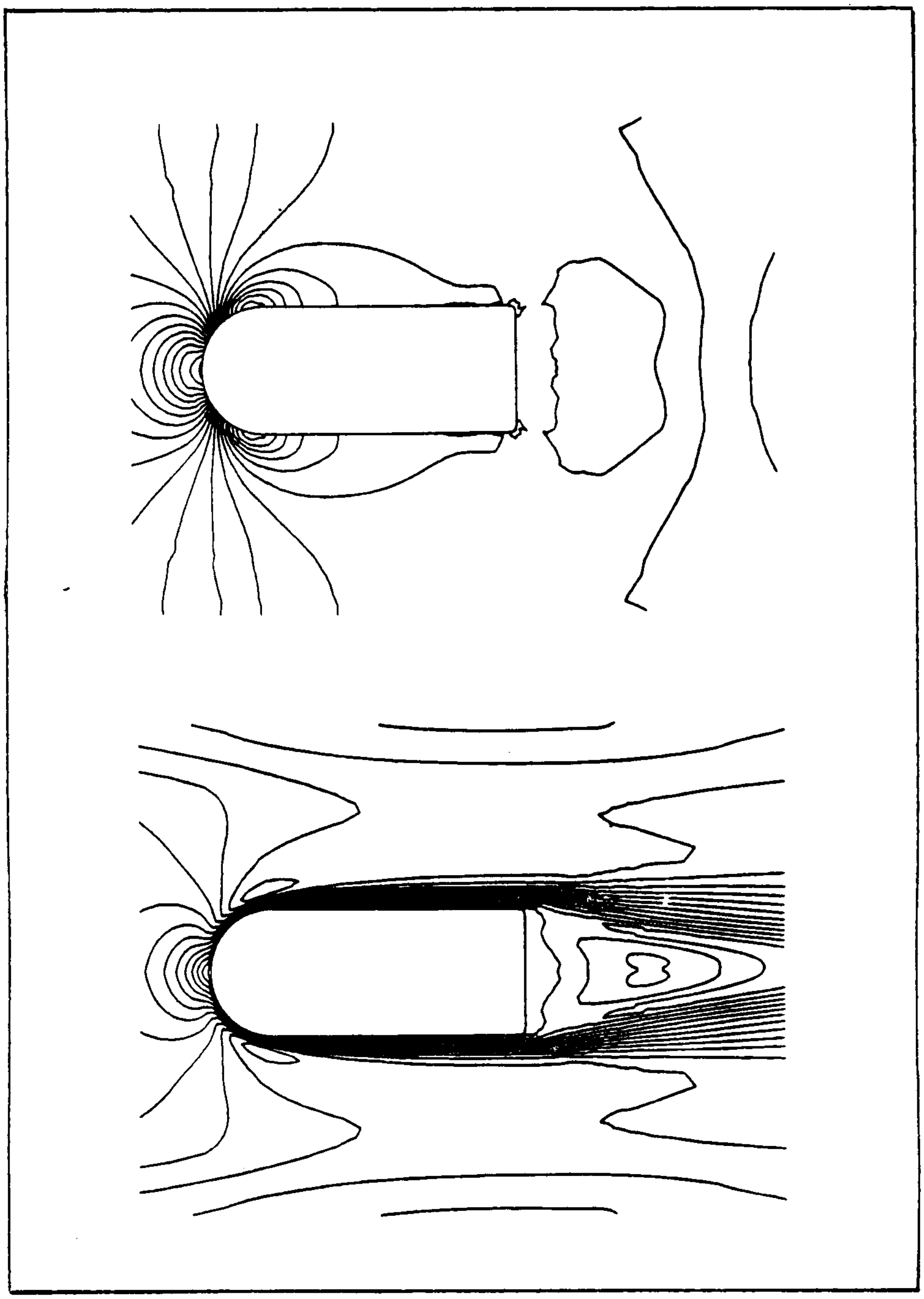


Fig. 3-13 Static Pressure Contours (Top) and Velocity Magnitude Contours for Strut in Annular Channel at Mid-Channel

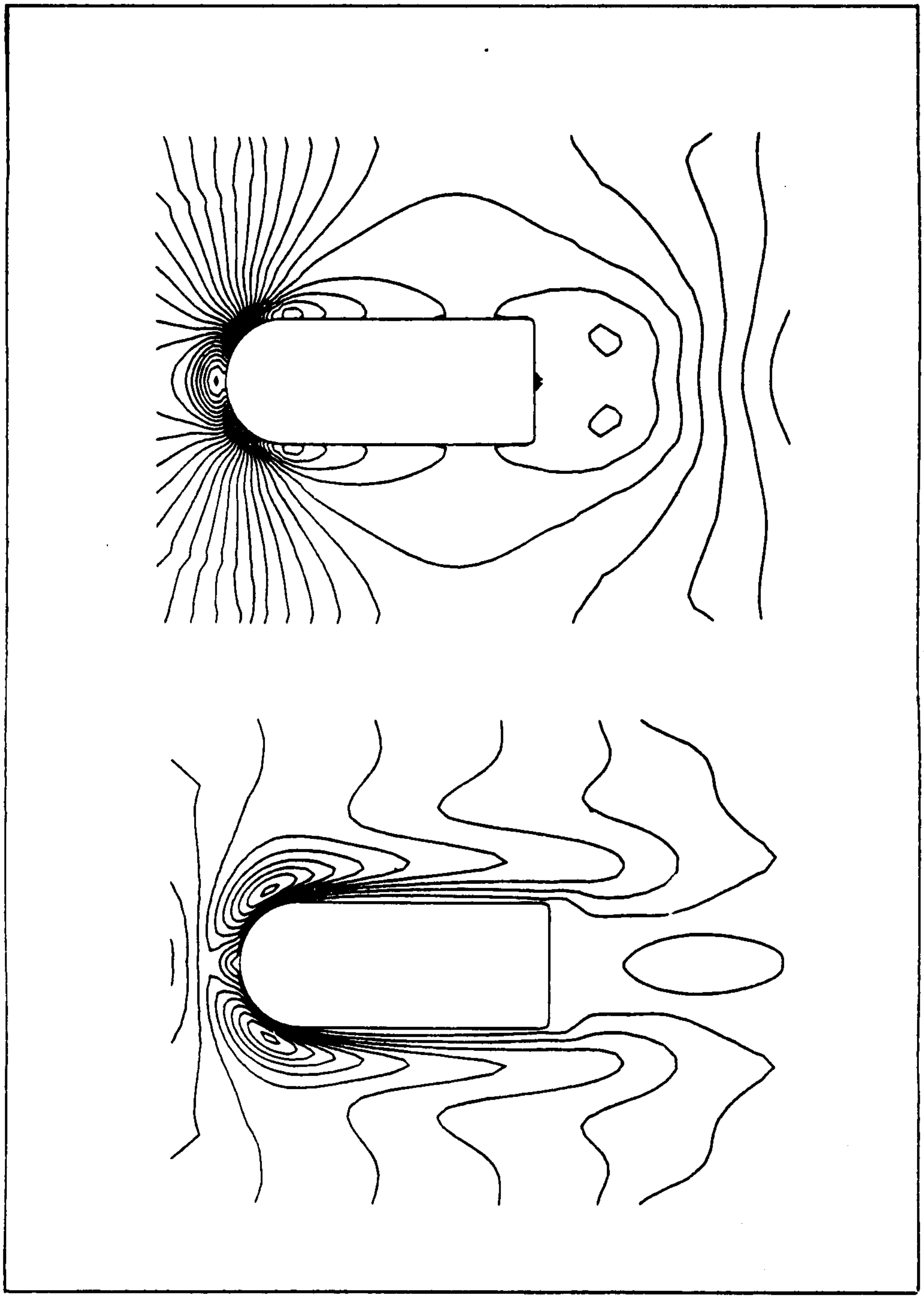


Fig. 3-14 Static Pressure Contours (Top) and Velocity Magnitude Contours for Strut in Annular Channel near Upper Wall

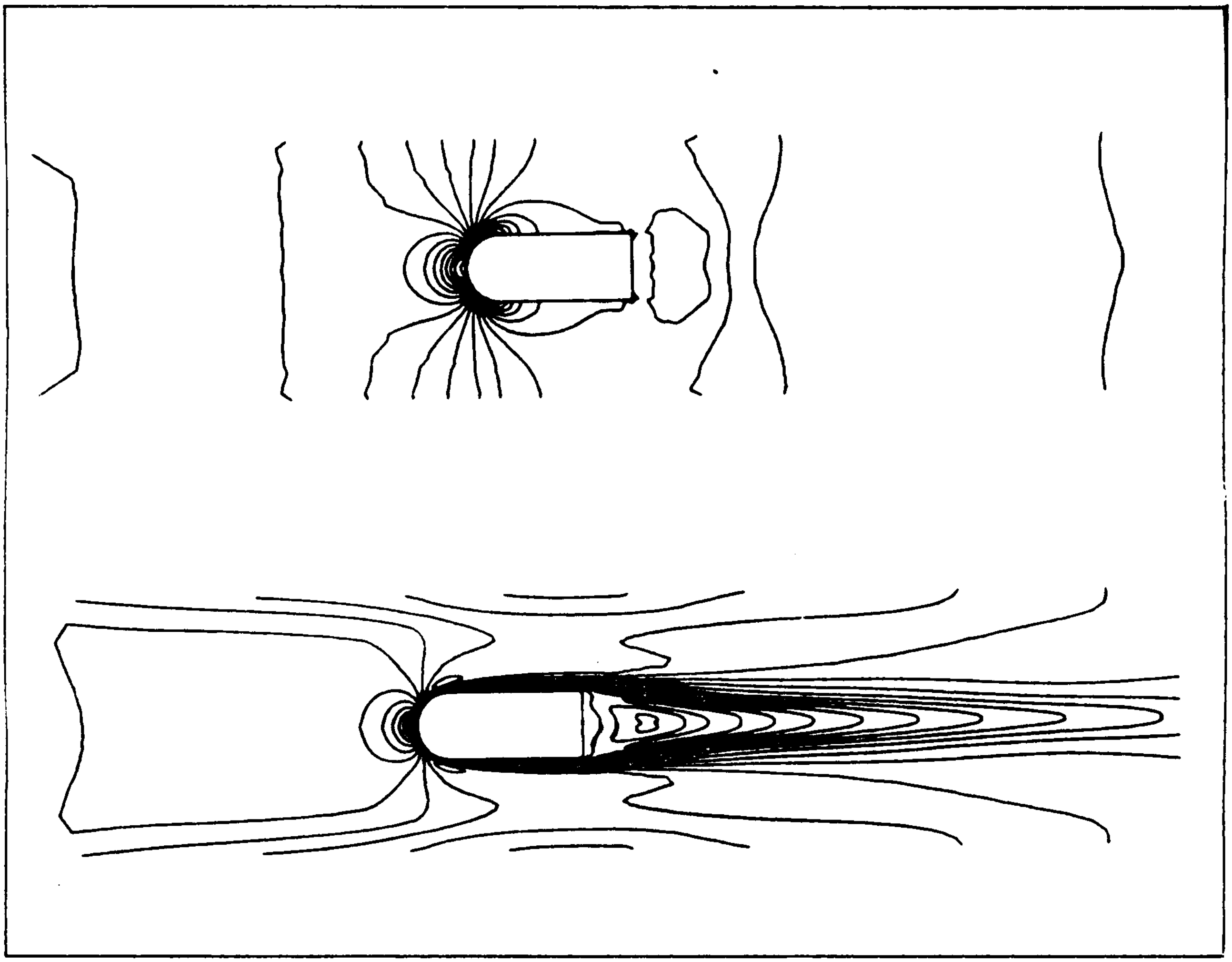


Fig. 3-15 Static Pressure Contours (Top) and Velocity Magnitude Contours for Entire Length of Computational Circumferential Plane at Mid-Channel

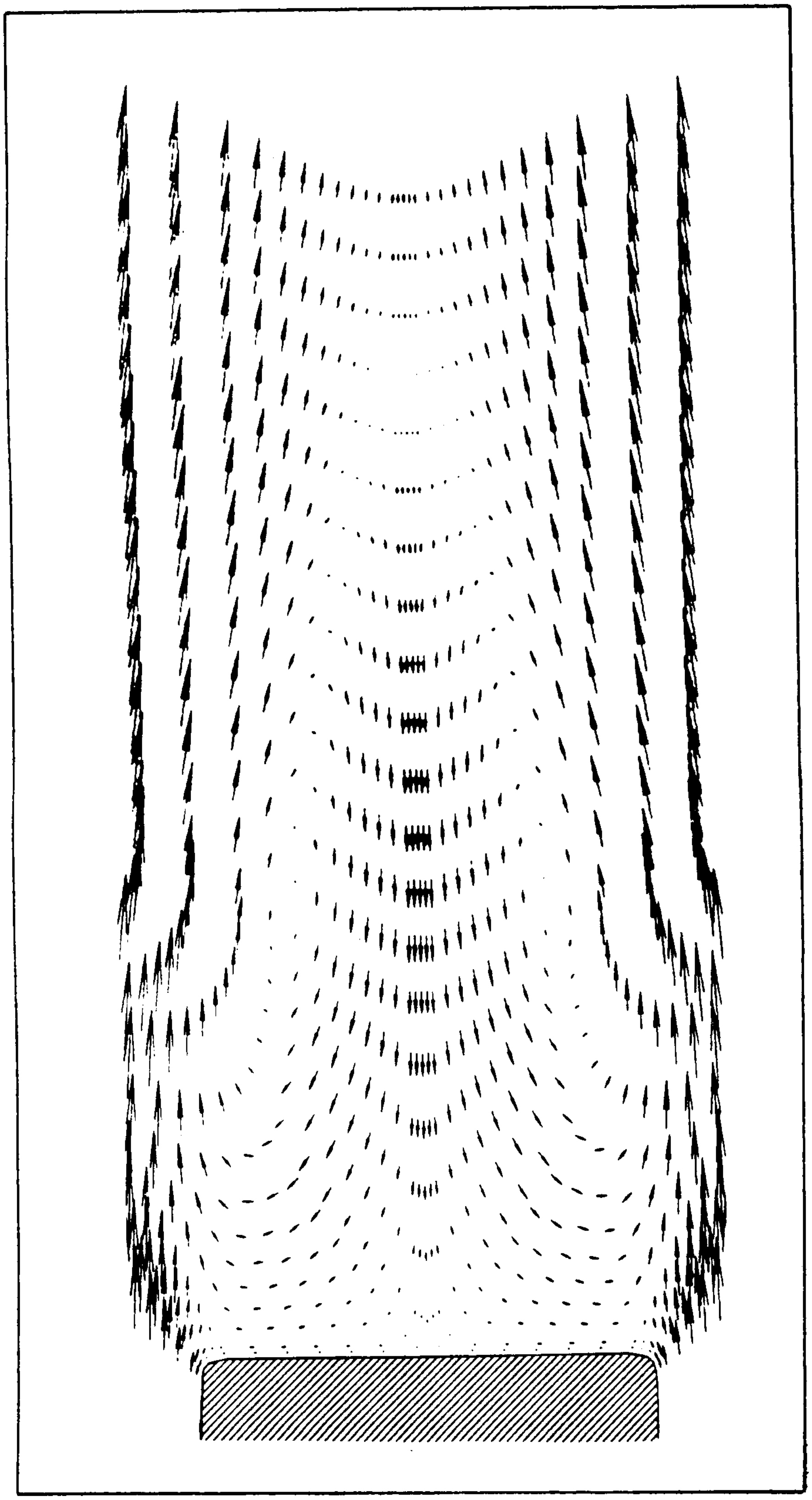


Fig. 3-16 Velocity Vectors in near Wake Region in a Central Plane for Case of Strut in Annular Channel (Mean Flow is from Left to Right)

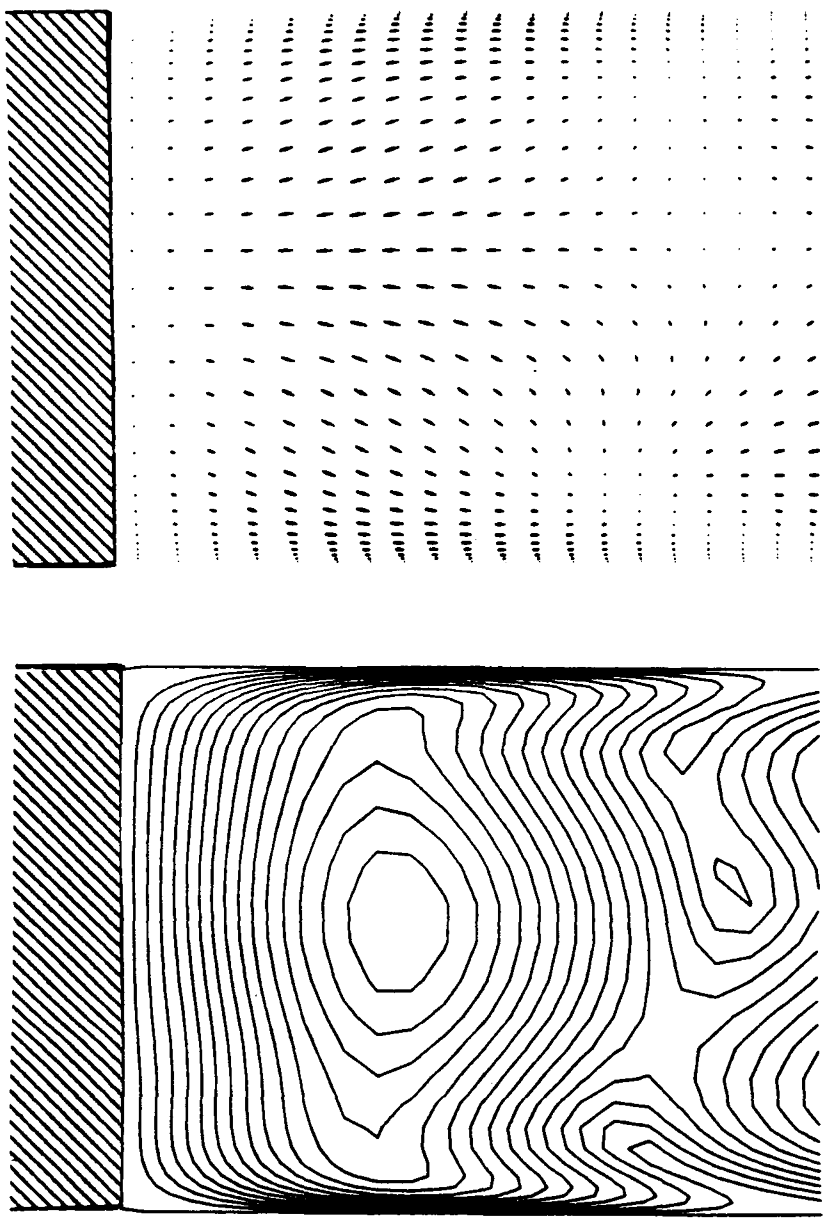


Fig. 3-17 Velocity Vectors (Top) and Velocity Magnitude Contours in Central Radial Plane in near Wake Region Behind Strut in Annular Channel (Mean Flow is from Left to Right)

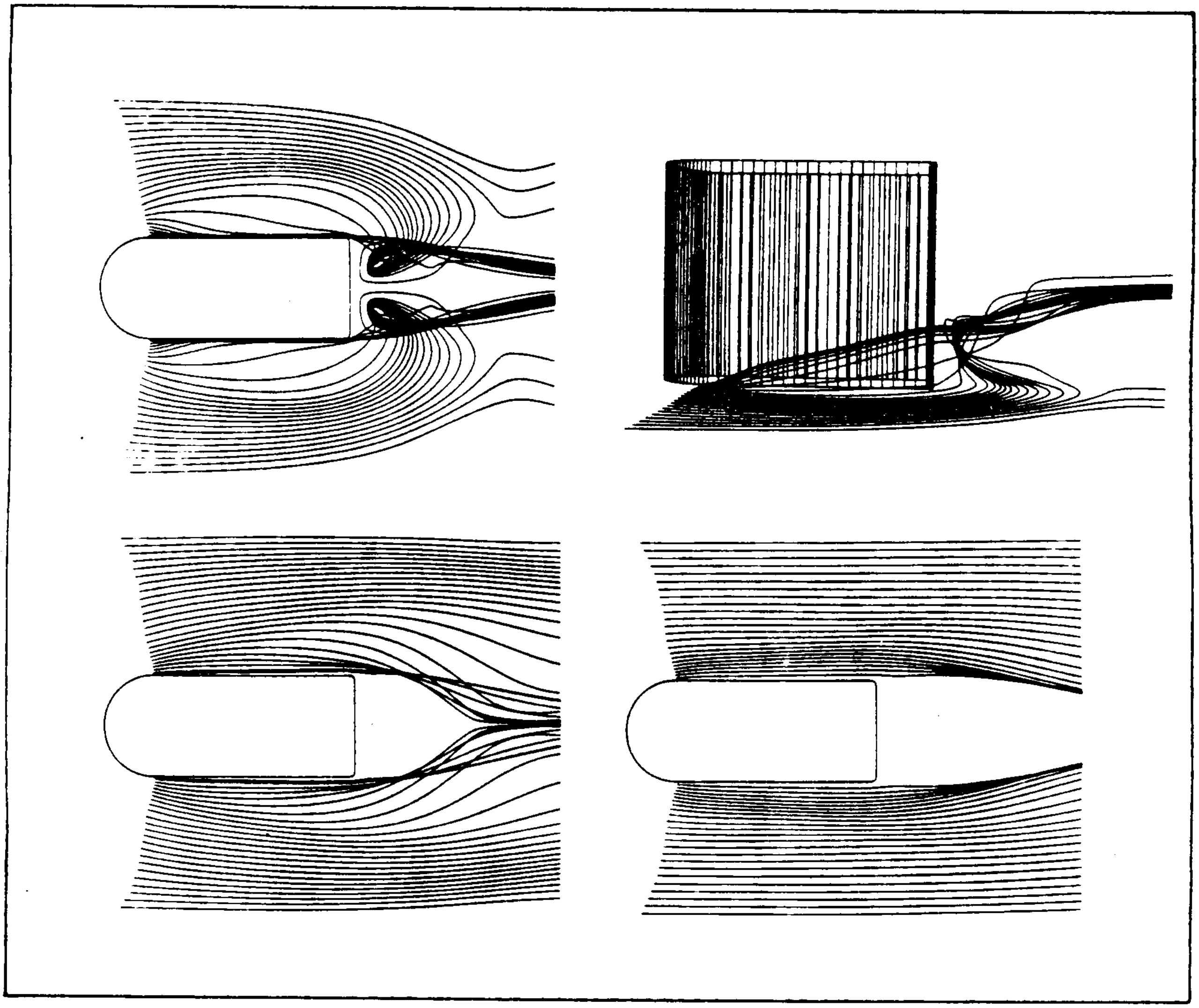


Fig. 3-18 Particle Traces for Flow Past Strut in Annular Channel Showing Paths of Particles Released near Front of Strut in a Plane near the Inner Wall (Top), one Quarter Channel Height Above Inner Wall (Bottom Left) and Mid-Channel

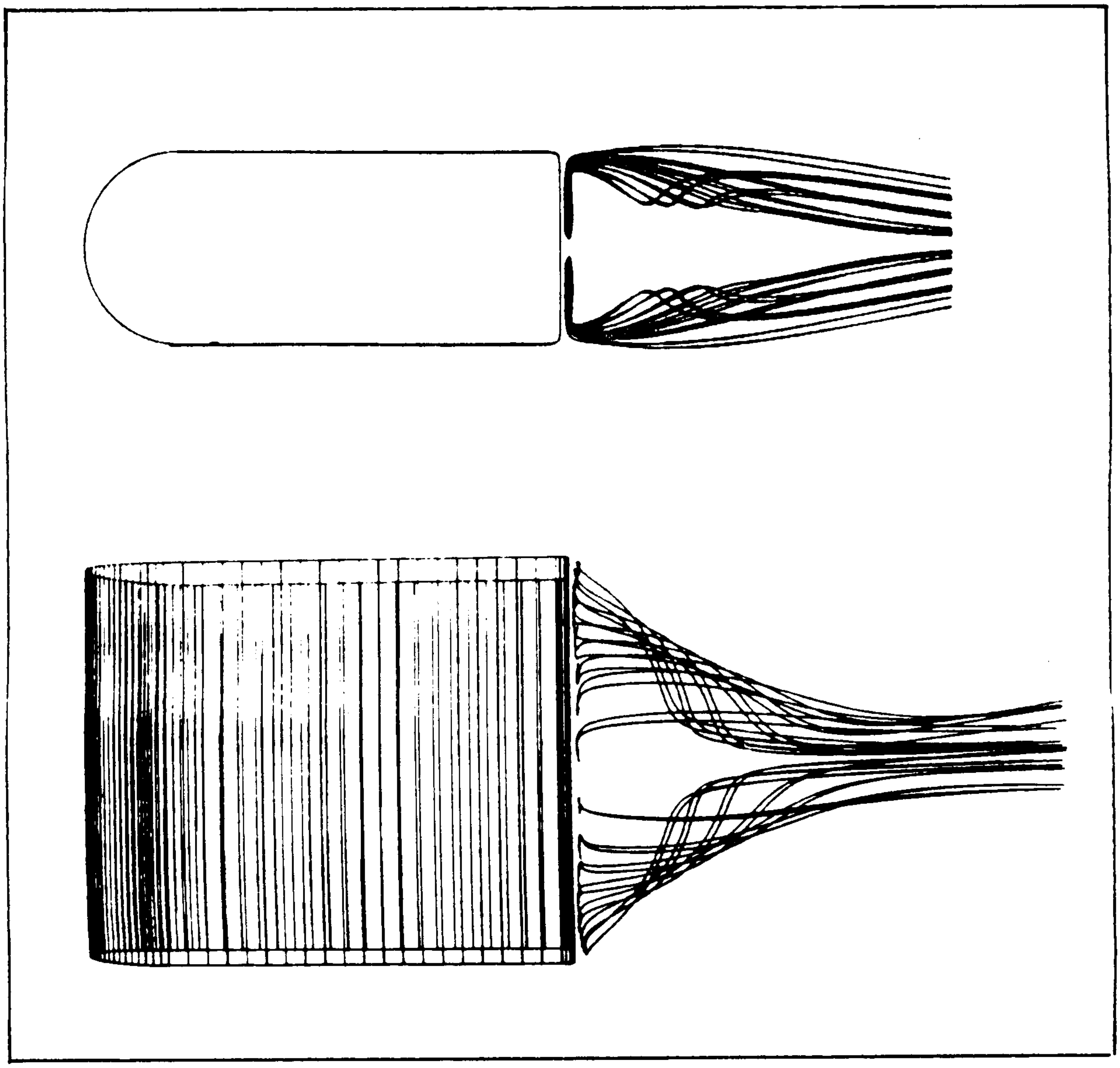


Fig. 3-19 Particle Traces of Particles Released near Rear Surface of Strut

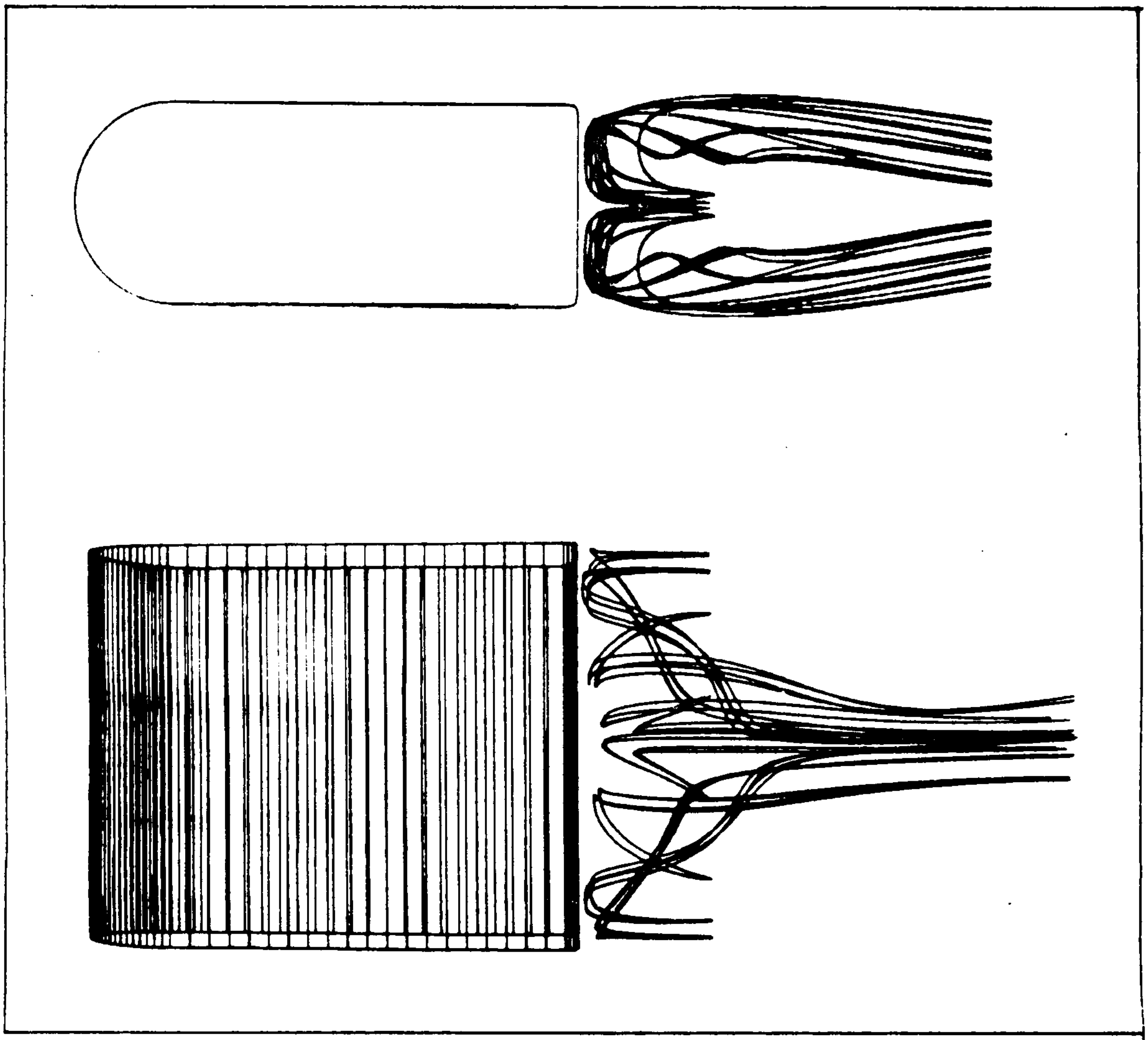


Fig. 3-20 Particle Traces of Particles Released near Central Radial Plane but just Downstream of Strut Rear Surface

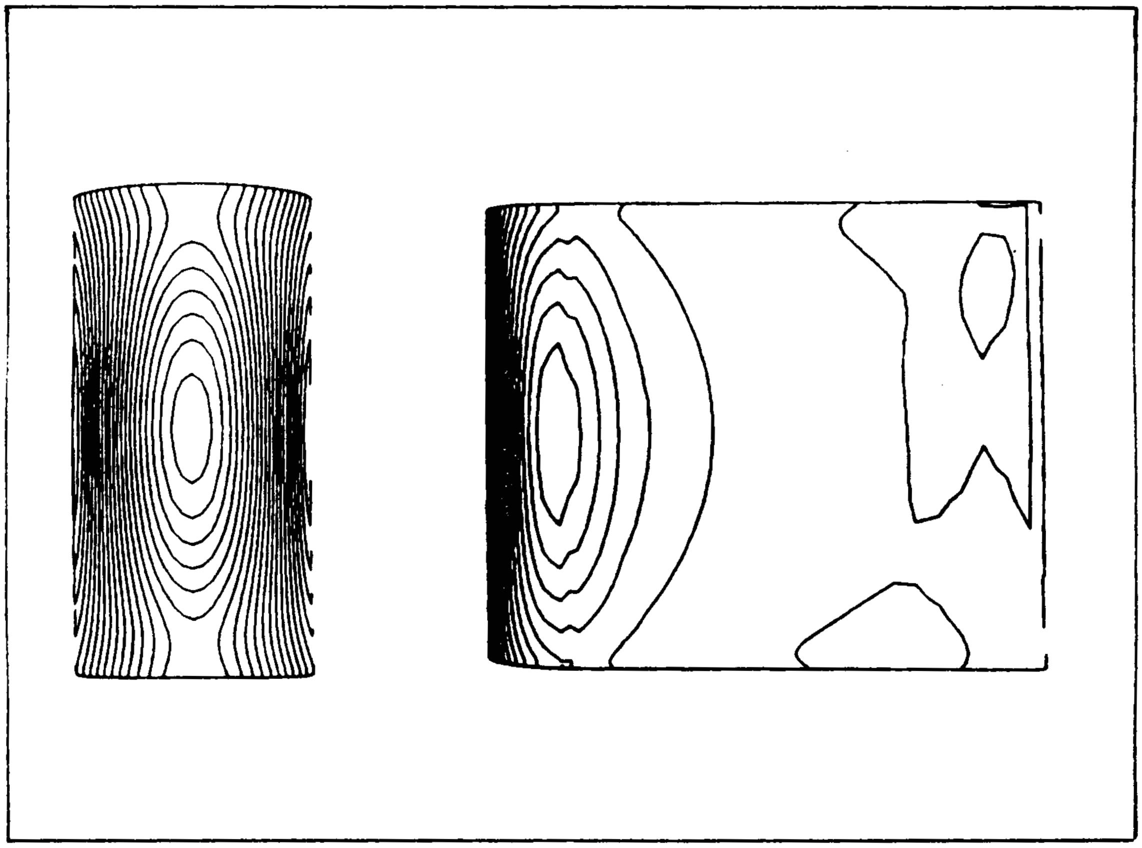


Fig. 3-21 Surface Pressure Contours on Strut Front Surface (Left, Flow into Page) and Side Surface (Right, Flow Left to Right)

4. CONCLUDING REMARKS

An elliptical two-duct SSME fuel side hot gas manifold geometry code has been developed for use by the Computational Fluid Dynamics Staff of NASA-MSFC. This report describes the methodology of the program, makes recommendations on the implementation, and provides an input guide, input deck listing, and source code listing for the code. The listing is well commented in order to assist the user in following its development and logic. A magnetic tape containing the source deck will be provided, upon request, to NASA-MSFC for use on its EADS network.

The NASA-Ames three-dimensional incompressible Navier-Stokes computational fluid dynamics code, INS3D, was obtained and implemented on the MSFC IBM/Cray computer facility. A low Reynolds number laminar calculation was performed with this code on a 162,006 node model of a strut in an annular channel. The dimensions were approximately those of the SSME/HGM fuel bowl entrance region which contains 12 such support struts circumferentially distributed in hot gas flow path. The computation was made as an initial step in a thorough numerical investigation of the influence of these obstacles on the flow exiting the manifold and impinging on the main injector LOX posts.

Results of this steady laminar computation indicate that a complete three-dimensional analysis of the whole manifold would require a "strut zone" for reliable predictions of of the transfer duct exit plane flow structure. This is especially evident since flow visualization results have shown that the duct flow is largely unsteady (Ref. 13).

5. REFERENCES

1. Thoenes, J., "Duct Flow Nonuniformities Study for Space Shuttle Main Engine," LMSC-HEC TR F042555, Lockheed Missiles & Space Company, Huntsville, Ala., August 1985.

2. Burke, R.W., "Duct Flow Nonuniformities - Effect of Struts in SSME HGM II+," LMSC-HEC TR F225961, Lockheed Missiles & Space Company, Huntsville, Ala., July 1988.

3. Kwak, D., J.L.C. Chang, S.P. Shanks, and S.R. Chakravarthy, "A Three-Dimensional Incompressible Navier-Stokes Flow Solver Using Primitive Variable," AIAA J., Vol. 24, No. 3, march 1986.

4. Roger, R.P., "Viscous Flow Computations for Elliptical Two-Duct Version of the SSME Hot Gas Manifold," LMSC-HEC TR D065161, Lockheed Missiles & Space Company, Huntsville, Ala., March 1986.

5. McConnaughey, P.K., "Comparison of Hot Gas Manifold Calculations, "Fifth SSME CFD Working Group Meeting, NASA-Marshall Space Flight Center, April 1987.

6. Chorin, A.J., "A Numerical Method for Solving Incompressible Viscous Flow Problems," J. Comp. Physics, Vol. 2, 1967, pp. 12-26.

7. Steger, J.L., and P. Kutler, "Implicit Finite-Difference Procedures for the Computation of Vortex Wakes," AIAA J., Vol. 15, No. 4, 1977, pp. 581-590.

8. Beam, R.M., and R.F. Warming, "An Implicit Finite-Difference Algorithm for Hyperbolic Systems in Conservation Law Form," J. Comp. Physics, Vol. 22, September 1976, pp. 87-110.

9. Warming, R.F., and R.M. Beam, "An Extension of A-Stability to Alternating Direction Implicit Methods," BIT, Vol. 19, 1979, p. 395.

10. Dwoyer, D.L., and F.C. Thames, "Accuracy and Stability of Time-Split Finite-Difference Schemes," AIAA Paper 81-1005, 1984.

11. South, J.C., "Recent Advances in Computational Transonic Aerodynamics," AIAA Paper 85-0366, 1985.

12. Briley, W.R., and R.C. Buggeln,and H. McDonald, "Solution of the Three-Dimensional Navier-Stokes Equations for a Steady Laminar Horseshoe Vortex Flow," AIAA Paper 85-1520, 1985.

13. Wiegman, B., J. Heaman, and P. Ramsey, "Water Flow Visualization Results on a phase III, One-Half Scale, SSME Hot Gas Manifold (HGM) with Sharp Corner Transfer Duct Inlets," CFD Workshop, NASA-Marshall Space Flight Center, November 1984.

Appendix A

HGM GRID CODE INPUT GUIDE

Appendix A

INTRODUCTION

This geometry input guide is presented in two sections: (1) a definition of terminology commonly used for inputting and describing the geometry, and (2) a summary of card types used to input the geometry and a detailed description of the associated parameters and their input values.

We begin with an overview of how to apply the program. The flowfield domain is divided into zones in order to simplify the input necessary to describe the complicated geometry. Each zone contains its own internal coordinate system, and is described using points, edges, and surfaces. An edge may consist of from one to ten segments. A segment or a surface may require special input depending on its type. This is the case for zones 2 and 3 of this two-duct HGM model.

The second section of this appendix presents a detailed description of the input parameters. Each card type is listed in the order of input with its associated parameters. Each parameter is identified as to its usage in the program with the options of each shown. Reference to Fig. A-1 or Table A-1 may be necessary to explain some of the input parameters and their order of input. All of the card types are not necessarily input for a specific zone, but may be set in specific subroutines in the program itself.

Card type 9 may be used when other than an equal distribution of nodes is desired, etc. Whereas card type 13 is necessary if there will be more than one segment per edge. And cards type 10 and 11 are used if additional information is needed to describe a segment or a surface. Certain of the input parameters on early cards dictate which of the later cards are read in.

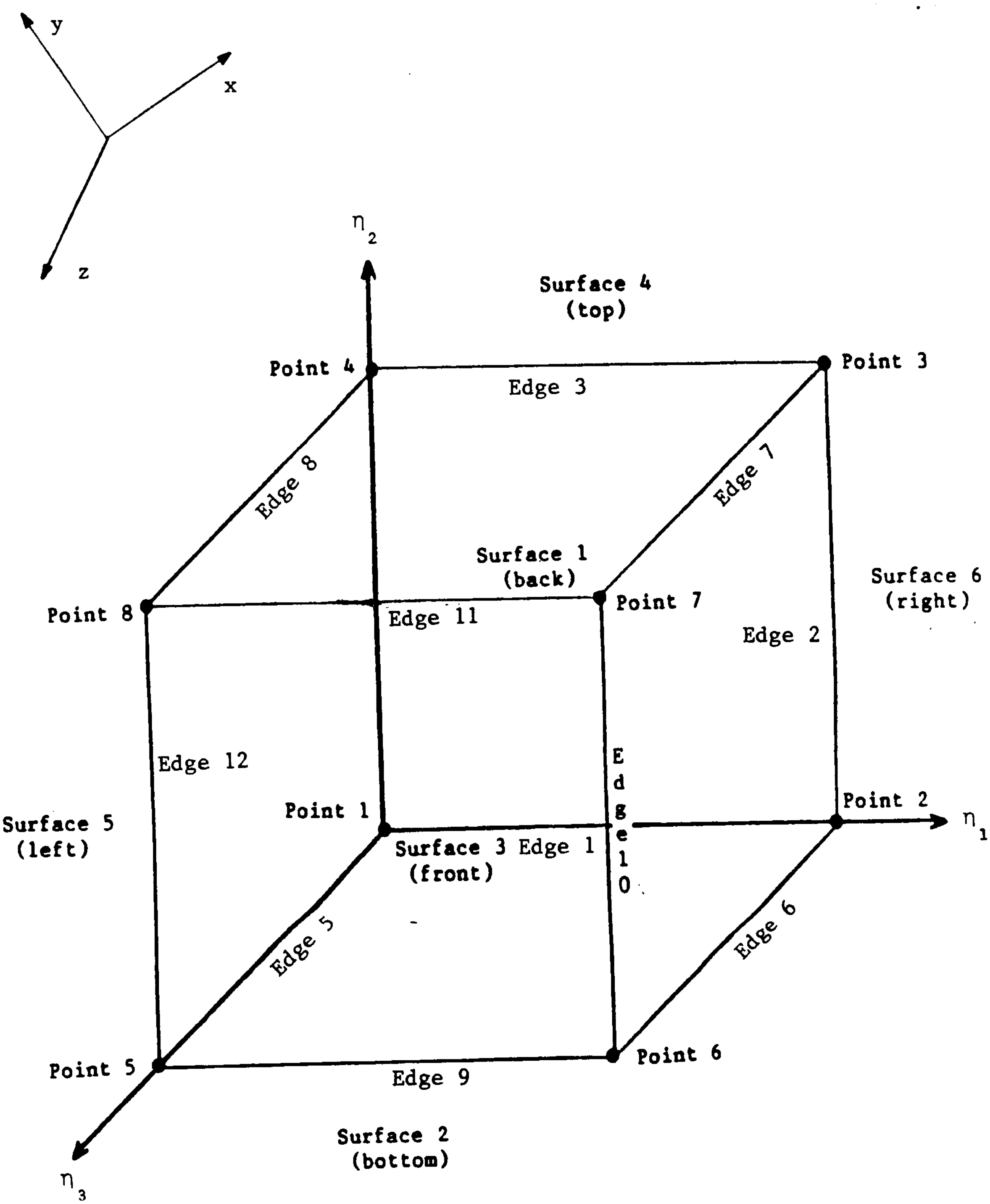


Fig. A-1 General Hexahedral: Numbering of Points, Edges, and Surfaces

DEFINITION OF TERMINOLOGY

Edge — An edge consists of from one to five segments. Twelve edges are used to describe a 3D zone.

Map — The geometry maps a point from η space into real space. When describing a surface mapping one could say that setting map = 2 refers to a planar η space surface being mapped onto a cylindrical surface in real space.

Node — At each intersection of η coordinates a node is generated by the program forming the grid which will describe the flowfield domain.

Point — The corners of a section are called "points." The location and initial flow directions are input for each point. There are eight points.

Segment — An edge is subdivided into as many as five segments. A segment may be a straight line, a circular arc, a helical coil, a trigonometric function of angle or length, a cubic spline, or user defined.

Surface — A three-dimensional section will consist of six surfaces which form a generalized hexahedron. A surface may be planar, cylindrical, an edge of revolution, or user defined.

Zone — The flowfield domain may be subdivided into zones. Zones are generated independently and are the fundamental building block. Each zone contains its own η coordinate system.

η_1, η_2, η_3 — Localized coordinate directions within a zone. These coordinates describe a cube in η space. $0 \leq \eta_I \leq 1$

SUMMARY OF CARDS

Card Type	Parameter List/Format
Flowfield Parameters	
1	ITITLE(I), I=1,80 (20A4)
2	NZONE, IZINDEX, MAPTEN, INCHES (8I5)
3	DCT1(I), DCT2(I), DCT3(I), I=1,37 (8F10.3)
Zone Parameter	
4	NSECT (I5)
Section Parameters	
5	MAPEDGE(I), I=1,12 (12I5) or (3(4I10))
6	MAPSIDE(I), I=1,6 (6I5)
7	MARCH (I5)
8	(NMBRNDS(I), I=1,3), (ISTRTCH(I), I=1,3) (6I5)
9	STRETCH(I), I=1,3 (3E10.4)
10	[(COEFE(I,K,J), I=1,8), K=1,5], J=1,4(2D) OR 12(3D) (8E10.4)
11	[COEFS(I,J),I=1,8], J=1,6 (8E10.4)
12	(POINT(I,J), I=1,3),J=1, 8 (8E10.4)
13	[(SEGMAX(I,K,J), I=1,3), ETAMAX(K,J), K=1,4] J=1, 12 (6E10.4)

CARD AND VARIABLE DESCRIPTIONS

Flowfield Parameters

CARD TYPE 1 Problem Identification Label Format(20A4)

ITITLE Alphanumeric information used for identifying the flowfield geometry. Columns 1-80 are read and printed only.

CARD TYPE 2 Problem Option Controls Flags Format(5I5)

NZONE The number of zones into which the flowfield geometry is divided. The maximum number of zones is 99.

IZINDEX Zone index for selecting individual components of the manifold to be computed.

= 1 zones 1 and 2 of Bowl
= 3, Transfer Duct
= 4 zones 4 and 5 of Turnaround Duct
= 6 all five zones

MAPTEN This option determines the maximum number of segments which will be input per edge.

= 0 Five segments per edge Format(12I5)
= 1 Ten segments per edge Format(3(4I10))

INCHES This option specifies the dimensions of the coordinates being input. The output data will be written in feet for compatibility with the INTEGRATION program.

= 0 Dimensions in feet
= 1 Dimensions in inches

Bowl Hole Parameters

CARDS TYPE 3a Angles, in degrees, about the axis of the transfer duct, measured counterclockwise from the x, z-plane as viewed down the z-axis.

CARDS TYPE 3b Radial distance difference (in inches) between transfer duct ellipse and hole perimeter along angular directions specified on cards 3a.

CARDS TYPE 3c Radius of curvature (in inches) at each angular distance, specified on cards 3a, for describing the transfer duct weld or fairing.

Zone Parameter

CARD TYPE 4 Index dividing zone data Format(I5)

NSECT Integer must be 1 and is used for separating data for each zone on the input file.

Section Parameters

CARD TYPE 5 Edge Shape Function Indicators Format(12I5) or 3(I10)

MAPEDGE(I), I=1, 12

These are packed integer flags that specify which edge shape functions will be used for the current section. The edges are input in numerical order. The edge numbers are defined according to Fig. A-1. The user should study this figure before inputting the geometry.

Each of the edges may consist of up to ten segments with each of these segments having its own shape function. The value of MAPEDGE(I) can consist of up to ten integers packed into one word MAPEDGE(I). MAPTEN specifies the maximum number of segments per edge. The edge shape function indicators for each segment are input in chronological order of increasing η for each edge with the final packed integer being right adjusted. For example, if MAPEDGE(4) = 112, then edge 4 consists of three segments: the first segment is type 1; the second segment is type 1; and the third segment is type 2. If only one segment describes an edge, then only one indicator is used, right adjusted.

A library of edge shape functions indicators for the HGM GEOMETRY program follow. If any edge shape function other than a linear segment is specified, then edge coefficients (COEFE(I)) must be input. Card type 1 is used to define the analytical function describing a segment.

= 1	Linear segment	
= 2	Circular arc	(input COEFE(I))
= 3	Conics	(input COEFE(I))
= 4	Edge of revolution	(input COEFE(I))
= 5	Special segment	(input COEFE(I))
= 6	Special segment	(input COEFE(I))
= 7	Special segment	(input COEFE(I))

CARD TYPE 6 Surface Shape Function Indicators Format(6I5)

<u>MAPSIDE(I),I=1,6</u>

These are integer flags that specify which surface shape functions will be used for the current section. These flags are input <u>only</u> for three-dimensional problems since two-dimensional geometries are defined completely by the edge functions. The surfaces are input in numerical order. The surface numbers are defined in Fig. A-1. The user should study this figure before inputting the geometry. An edge of revolution requires the input of surface coefficients (COEFS(I)) on card type 15 to define a relative origin on the axis, the axis of revolution, and the direction of revolution.

= 1	Planar surface	
= 2	Cylindrical surface	
= 3	Special surface	(user defined)
= 4	Edge of revolution	(input COEFS(I))
= 5	Hole in bowl surface	
= 6	Duct surface at bowl	
= 7	Duct fairing surface	

CARD TYPE 7 Node Numbering Sequence Specs Format(6I5)

MARCH(I5) The value of MARCH determines the node generation and hence the node numbering sequence. (default = 1)

The numbering sequence corresponding to follows.

= 1 η_3, η_2, η_1 (default)
= 2 η_1, η_3, η_2
= 3 η_2, η_1, η_3

CARD TYPE 8 Node Distribution Parameters Format(6I5)

NMBRNDS(I),I=1 3

NMBRNDS(I) is the number of nodes in the η_I direction for the current section. The limit is 200 nodes in any coordinate direction. This may be changed in the program by respecifying the ETAS(3,200) array.

ISTRTCH(I),I=1 3

This option gives the user control over the node distribution in each of the coordinate directions.

= 0 Uniform spacing
= 1 Input actual η_I values for NMBRNDS(I) nodes (input ETAS(I))
= 2 Decrease spacing in η_I direction. Input a stretching factor greater than 0.0 in STRETCH(I).
= 3 Increase spacing in η_I direction. Input a stretching factor greater than 0.0 in STRETCH(I).
= 4 Double stretching. Input a stretching factor greater than 0.0 in STRETCH(I). Use an odd number of nodes.
= 5 Decrease spacing in η_I direction. Input minimum grid spacing as a percentage of the total length in STRETCH(I).
= 6 Increase spacing in η_I direction. Input minimum grid spacing as a percentage of the total length in STRETCH(I).
= 7 Double stretching. Input minimum grid spacing as a percentage of the total length in STRETCH(I). Use an odd number of nodes.

If ISTRTCH(I) = 1, input a set of cards type 13 for each η direction to be input.
If ISTRTCH(I) $\geq$ 2, input card type 12.

CARD TYPE 9 Option for Stretching Function (input when ISTRTCH(I) $\geq$ 2) Format(3E10.4)

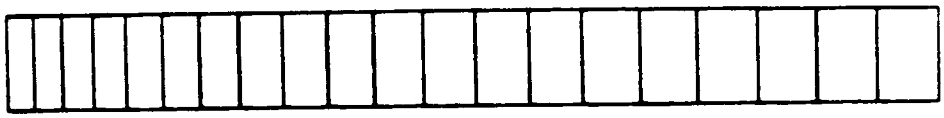
STRETCH(I),I=1, 3

This parameter is input for each coordinate direction designated for stretching by ISTRTCH(I) $\geq$ 2.

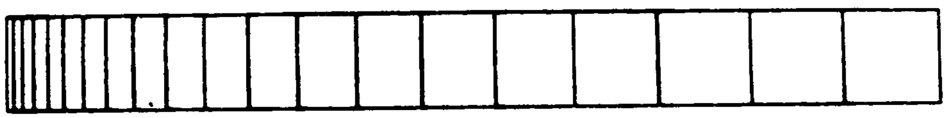
Example: Several stretching functions will be demonstrated using 21 points for comparison. Note, that total length = 10.0 for ISTRTCH = 6 and 7.

ISTRTCH = 3

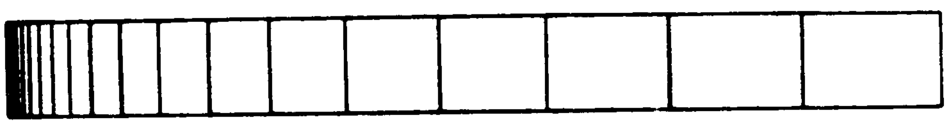
STRETCH = 2.0



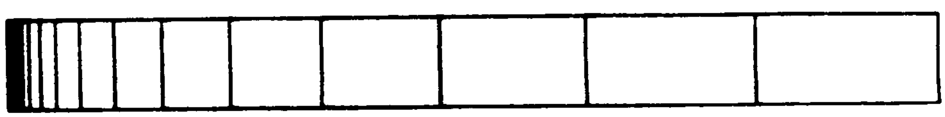
STRETCH = 4.0



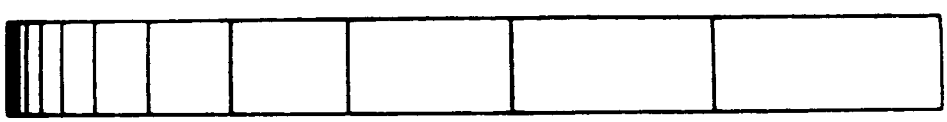
STRETCH = 6.0



STRETCH = 8.0

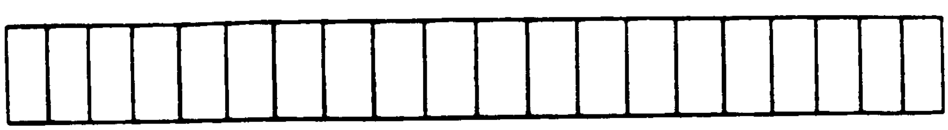


STRETCH = 10.0

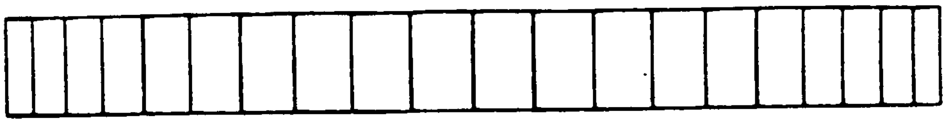


ISTRTCH = 4

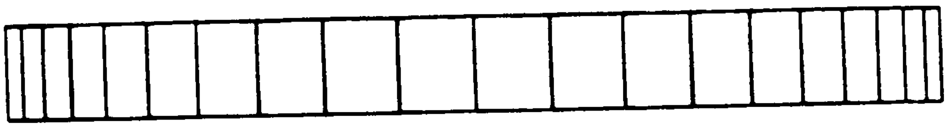
STRETCH = 2.0



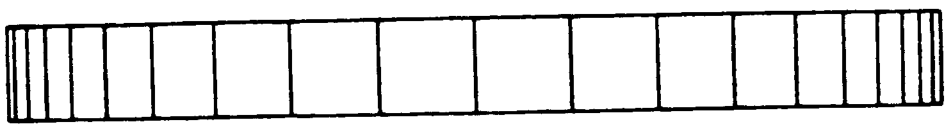
STRETCH = 4.0



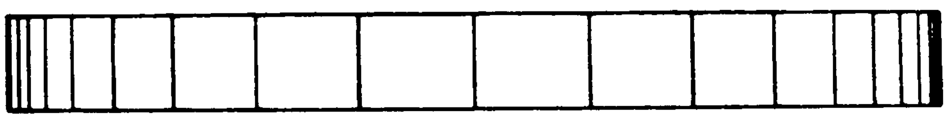
STRETCH = 6.0



STRETCH = 8.0

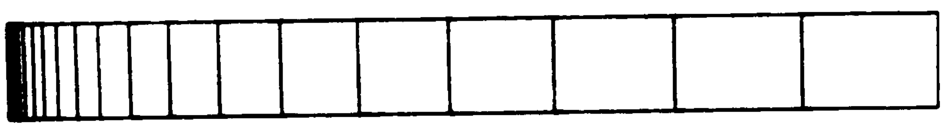


STRETCH = 10.0

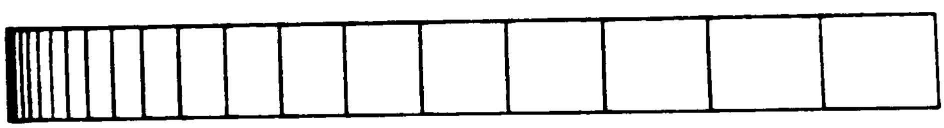


ISTRTCH = 6

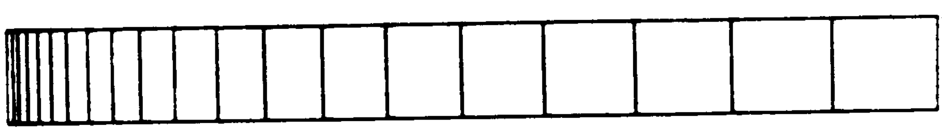
STRETCH = .002



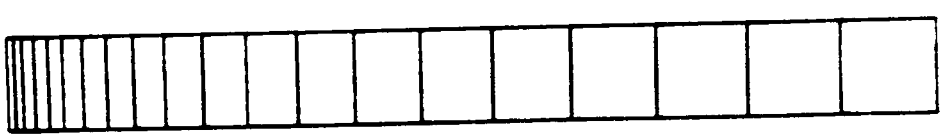
STRETCH = .004

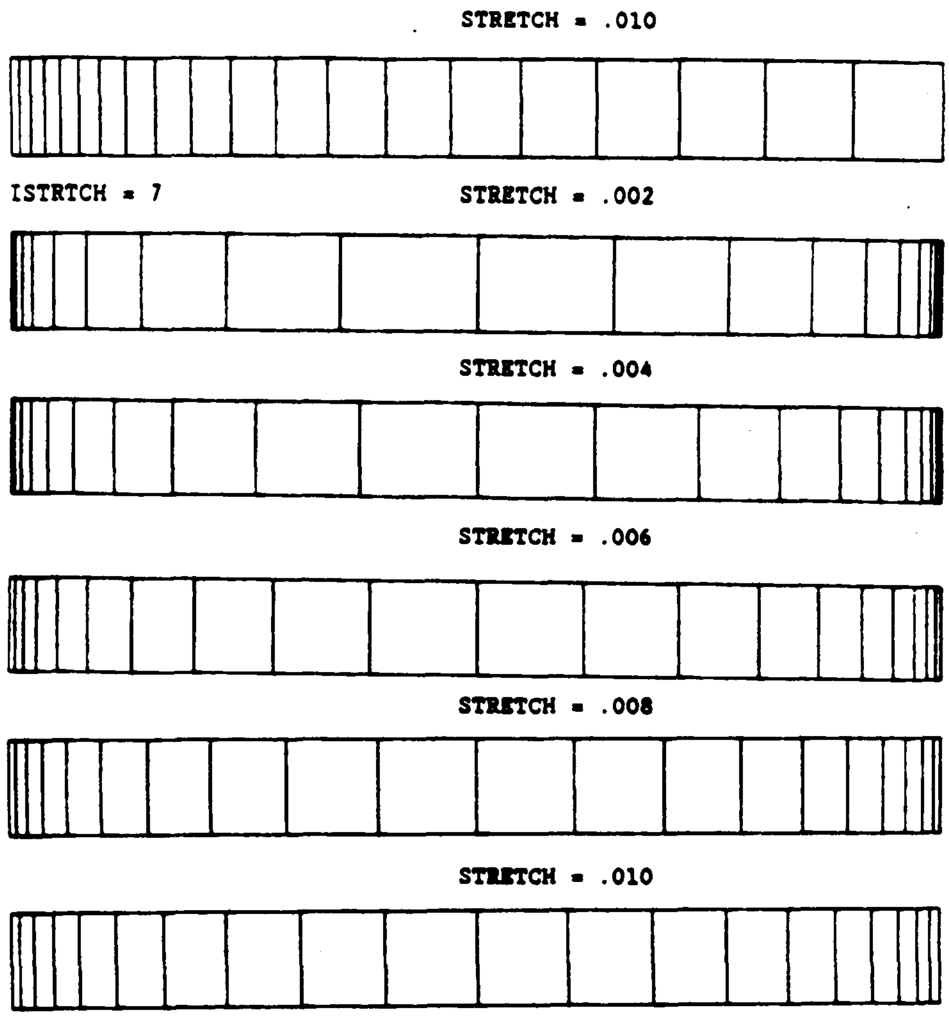


STRETCH = .006



STRETCH = .008





CARD TYPE 14 Coefficients for Edge Shape Functions (input for each segment in MAPEDGE(I) > 1) Format(8E10.4)

<u>COEFE(I),I=1,8</u>

These coefficients are used to describe the edge shape functions for each segment of the current section. The coefficients for each segment are input on <u>separate cards</u> in the same order as the indicators on card type 5.

Map	Type	Input Parameters
2	Circular Arc	COEFE(I), I=1,3 are the x, y, and z coordinates of the center of the arc.
3	Edge of Revolution	COEFE(I), I=1,3 are coordinates of the center of the arc. COEFE(I), I=4,6 are components of the unit vector along the axis. Direction according to right hand rule when a vector is revolved from point 1 to point 2.

CARD TYPE 15 Coefficients for Surface Shape Functions (input when MAPSIDE(I) = 4 and IDIM = 3) Format(8E10.4)

COEFS(I),I=1,8

These are the coefficients defining the surface shape functions for each surface formed by an edge of revolution in the current section. Each surface which has MAPSIDE(I) = 4 on card type 8 is input on a separate card in the same order as they occur on card type 8.

Map	Type	Input Parameters
4	Surface of Revolution	Surface formed by revolving an edge about an axis. COEFS(I), I=1,3 a point on the axis of revolution which becomes the origin of a local coordinate system. This point must lie outside of the projection of the edge onto the axis of revolution. COEFS(I), I=4,6 are components of the unit vector along the axis of revolution in the direction of increasing n. COEFS(7) indicates the η_I direction in which the edge will revolve.

CARD TYPE 16 Coordinates of Points Format(5E10.4)

POINT(I,J), J = Point number

These parameters are the coordinates and flow direction at each corner of a general hexahedral(3D). Figure A-1 shows this configuration with the points numbered from 1 to 8. There are eight cards of type 16 to be input.

POINT(1,J) - the x coordinate of point J

POINT(2,J) - the y coordinate of point J

POINT(3,J) - the z coordinate of point J

Important Note: All cards type 12 are not input consecutively. They are grouped with cards type 13. See Table A-1 for the exact sequence of card types 11 and 13.

CARD TYPE 17 Segment Extremals for Edges Format(6E10.4)

SEGMAX(I,K,J), K = Segment Number, J = Edge Number

Each edge may be segmented up to five times. Therefore, cards type 13 are repeated for each successive segment of edge J. Each segment must be input on a separate card type 13. The extremal for the final segment of an edge is not to be input since this point is already defined by the POINT(I) input. The number of cards type 13 for each edge will thus be one less than the number of segments on that edge. In particular, if an edge consists of only one segment, no cards of type 13 are input for that edge.

See Table 1 for the input order of card types 12 and 13. Each POINT(I) is input on a single card, followed by up to five cards containing the extremals.

SEGMAX(1,K,J) - The extremal x coordinate for the K^{th} segment of edge J.
SEGMAX(2,K,J) - The extremal y coordinate for the K^{th} segment of edge J.
SEGMAX(3,K,J) - The extremal z coordinate for the K^{th} segment of edge J.

ETAMAX(K,J), K= Segment Number, J= Edge Number

The maximum value of the η_I coordinate on the K^{th} segment of edge J. Input a negative value when defining a fold line.

Appendix B
HGM GRID CODE INPUT LISTING

```
  TWO DUCT HGM II+
  2    1    0    1
   0.0       10.0       20.0       30.0       40.0       50.0       60.0       70.0
  80.0       90.0      100.0      110.0      120.0      130.0      140.0      150.0
 160.0      170.0      180.0      190.0      200.0      210.0      220.0      230.0
 240.0      250.0      260.0      270.0      280.0      290.0      298.0      310.0
 320.0      330.0      340.0      350.0      360.0      ANGLE
   0.30       0.29       0.28       0.25       0.23       0.20       0.16       0.12
   0.06       0.05       0.06       0.12       0.20       0.28       0.37       0.46
   0.55       0.66       0.76       0.90       1.25       1.85       2.45       2.35
   1.85       1.32       1.00       0.95       1.05       1.30       1.649      1.00
   0.75       0.55       0.43       0.35       0.30       DIFFERENCE
   2.0        2.0        2.0        2.0        2.0        2.0        2.0        2.0
   2.0        2.0        2.0        2.535      3.069      3.604      4.139      4.673
   4.673      4.673      4.673      3.81       3.151      2.744      2.684      2.801
   3.055      3.596      4.2        4.253      3.509      2.54       1.942      2.0
   2.0        2.0        2.0        2.0        2.0        CURVATURE
   1                                                   BOWL           ZONE 1
 111    1  113    1    4    4    4    4  111    111333    1
   1    4    1    4    1    4
   3
  58   21   36    0    4    0
      0.0       6.0       0.0
   1                                        BOWL WITH HOLE            ZONE 2
 111     111333   1    4    4  444  444  111    111113    1
   1    4    1    5    1    1
   3
  58   21   74    0    4    0
      0.0       6.0       0.0
   1                                                   DUCT           ZONE 3
   7   91    8   91    7    7    8    8    7   91    8   91
   7    6    7    1    7    7
   2
  30   59   44    4    0    4
      6.0       0.0       4.0
   1                                                   TAD # 1        ZONE 4
  12    1   12    1   22   22 2222 2222   12    1   12    1
   1    2    1    2    1    2
   1
  30   21  109    0    0    0
   1                                                   TAD # 2        ZONE 5
 211    1  211    1   22   22 2222 2222  211    1  211    1
   1    2    1    2    2    1
   1
  42   21  109    0    0    0
/EOR
```

Appendix C

HGM GRID CODE LISTING

```
C***********************************************************************
C*****MAIN**************************************************************
C***********************************************************************
C
C      PROGRAM HGM2DUCT(INPUT,OUTPUT,FILE20,TAPE5,TAPE6=OUTPUT,
C     &                TAPE20=FILE20)
C
      PROGRAM HGM2DUCT
C-----------------------------------------------------------------------
C   ELLIPTICAL TWO-DUCT HOT GAS MANIFOLD GRID CODE
C   DEVELOPED BY THE COMPUTATIONAL MECHANICS SECTION
C   LOCKHEED ENGINEERING CENTER, HUNTSVILLE, ALABAMA.
C   TAPE20 GEOMETRY DATA
C-----------------------------------------------------------------------
      COMMON /COUNTER/ NODESAV,NODETOT,NBNODES,NPLANE
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
      COMMON /UNITS/   NU5,NU6,NU20
C
C---INITIALIZE PROGRAM
C
      CALL INITIAL(NZONE)
C
C-----------------------------------------------------------------------
C   ZONE
C-----------------------------------------------------------------------
      DO 300 IZONE=1,NZONE
C
      READ(NU5,1000) NZINDEX
C
C---READ INPUT FOR EACH ZONE
C
      CALL INPUT
C
C---GENERATE MESH FOR EACH ZONE
C
      CALL MESH
C
  300 CONTINUE
C
C---PRINT FILE STATUS
C
      CALL STATUS(0)
C
      STOP
C
C---FORMAT STATEMENTS
C
 1000 FORMAT(I5)
C
      END
C
C***********************************************************************
C*****INPUT*************************************************************
C***********************************************************************
C
      SUBROUTINE INITIAL(NZONE)
C
      COMMON /COEFF/   COEFE(8,10,12),COEFS(8,6),NMBRSEG(12)
      COMMON /COUNTER/ NODESAV,NODETOT,NBNODES,NPLANE
```

```
      COMMON /HEADER/  ITITLE(20),LINE
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /INITB/   IBOX(4,6),IRAY(4,3),NRAY,IPT1(12),IPT2(12)
      COMMON /INITC/   PI,RADDEG
      COMMON /NODNMBR/ NODENUM(4000),TOL(3)
      COMMON /UNITS/   NU5,NU6,NU20
C
      DIMENSION NAME(20)
C
      DATA PI      /3.141592654/
      DATA RADDEG /57.29577951/
      DATA IPT1 /1,2,4,1,1,2,3,4,5,6,8,5/
      DATA IPT2 /2,3,3,4,5,6,7,8,6,7,7,8/
      DATA IRAY /1,3,9,11,4,2,12,10,5,6,8,7/
      DATA IBOX /4,1,2,3,5,1,6,9,12,9,10,11,8,3,7,11,5,4,8,12,6,2,7,10/
C
C-----------------------------------------------------------------------
C     INITIALIZE
C-----------------------------------------------------------------------
C
               NU5   = 5
               NU6   = 6
               NU20  = 20
              MUNIT  = 20
C
             NPLANE  = 0
            NBNODES  = 0
            NINODES  = 0
            NODETOT  = 0
            NODESAV  = 0
C
C---COEFFICIENTS
C
      DO 20 I=1,8
C
      DO 10 J=1,6
   10   COEFS(I,J) = 0.0
C
      DO 20 J=1,10
      DO 20 K=1,12
   20 COEFE(I,J,K) = 0.0
C
C-----------------------------------------------------------------------
C   NZONE      = NUMBER OF ZONES TO BE USED TO GENERATE MESH
C   IZINDEX    = NO OF THE ZONE TO BE COMPUTED
C              = 1 DO ZONES 1 & 2
C              = 3 DO ZONE 3
C              = 4 DO ZONES 4 & 5
C              = 6 DO ALL FIVE ZONES
C   MAPTEN     = 0 FIVE SEGMENTS PER EDGE
C              = 1 TEN SEGMENTS PER EDGE
C   INCHES     = 0 COORDINATES INPUT IN FEET
C              = 1 COORDINATES INPUT IN INCHES
C-----------------------------------------------------------------------
C
C---ECHO INPUT
C
      WRITE(NU6,1100)
C
      DO 90 I=1,500
```

```
      READ(NU5,1000,END=100) NAME
   90 WRITE(NU6,1110) NAME
C
  100 REWIND NU5
C
C---PRINT HEADER
C
      WRITE(NU6,1120)
C
C---READ PROBLEM DEFINITION
C
      READ(NU5,1000) ITITLE
      READ(NU5,1010) NZONE,IZINDEX,
     &               MAPTEN,INCHES
C
C---WRITE PROBLEM DEFINITION
C
      NRAY = 4
C
                     WRITE(NU6,1130) ITITLE
                     WRITE(NU6,1140) NZONE,IZINDEX,
     &                               MAPTEN,INCHES
C
      CALL RWIND(NU20)
C
C---DRAW PICTURE
C
      IDIM = 3
      CALL PICTURE(IDIM)
C
C---HGM TWO DUCT DATA
C
      CALL DCTDAT
C
      RETURN
C
 1000 FORMAT(20A4)
 1010 FORMAT(16I5)
 1100 FORMAT(1H1,25X,17H INPUT DATA IMAGE // )
 1110 FORMAT(5X,20A4)
 1120 FORMAT(1H1
     3    / 40X,34H                LOCKHEED-HUNTSVILLE
     4    / 40X,34H                 VAX 11/785 VERSION
     5    / 40X,38H            2-DUCT HGM  GEOMETRY MODULE   )
 1130 FORMAT(/  12H CASE TITLE: // 5X,20A4 )
 1140 FORMAT(// 21H GEOMETRY PARAMETERS:
     1       // 23H     NZONE      IZINDEX,
     2          22H     MAPTEN    INCHES ,// 6I10 )
C
      END
C
C***********************************************************************
C*****INPUT*************************************************************
C***********************************************************************
C
      SUBROUTINE INPUT
C
      COMMON /COEFF/   COEFE(8,10,12),COEFS(8,6),NMBRSEG(12)
      COMMON /COUNTER/ NODESAV,NODETOT,NBNODES,NPLANE
      COMMON /HEADER/  ITITLE(20),LINE
```

```
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /INITB/   IBOX(4,6),IRAY(4,3),NRAY,IPT1(12),IPT2(12)
      COMMON /INPUTA/  EDGE(3,12),POINT(3,8),SIDE(3,6)
      COMMON /MAPING/  MAPSIDE(6),MAPSEG(10,12)
      COMMON /MARCHS/  MARCH,INDEX(3)
      COMMON /MAXIMUM/ ETAMAX(10,12),SEGMAX(3,10,12)
      COMMON /NODNMBR/ NODENUM(4000),TOL(3)
      COMMON /SPACING/ ISTRTCH(3),STRETCH(3),ETAS(3,200),ETA(3),DETA(3)
      COMMON /UNITS/   NU5,NU6,NU20
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
C
      DIMENSION IFLAGP(8),IFLAGE(12),IFLAGS(6)
      DIMENSION LSTRTCH(3),LBCINPT(6),LMAPS(6)
      DIMENSION MAPEDGE(12),STRTCH(3),LNMBRND(3)
C----------------------------------------------------------------------
C    MAPEDGE(I)    INDICATES TYPE OF GEOMETRY FOR EDGE I
C                  = 1 LINEAR
C                  = 2 CIRCULAR ARC
C                  = 3 CONIC(PARABOLA,ELLIPSE,HYPERBOLA)
C                  = 4 HELICAL ARC
C                  = 5 TRIG FUNCTION OF X
C                  = 6 TRIG FUNCTION OF ANGLE
C                  = 7 CUBIC POLYNOMIAL
C
C    MAPSIDE(I)    TYPE OF GEOMETRY FOR SURFACE I
C                  = 1 FLAT SURFACE
C                  = 2 CYLINDRICAL SURFACE
C                  = 4 EDGE OF REVOLUTION
C
C    MARCH         ETA DIRECTION IN WHICH COMPUTATION IS TO ADVANCE
C
C    NMBRNDS(I)    NUMBER OF NODES IN EACH ETA(I) DIRECTION
C
C    ISTRTCH(I)    = 0 NO STRETCHING IN ETA(I) DIRECTION
C                  = 1 INPUT VALUES OF ETA(I) (N)
C                  = 2 DECREASE SPACING IN ETA(I) DIRECTION (INPUT FACTOR)
C                  = 3 INCREASE SPACING IN ETA(I) DIRECTION (INPUT FACTOR)
C                  = 4 DOUBLE STRETCHING (INPUT FACTOR)
C                  = 5 DECREASING SPACING IN ETA(I) DIRECTION (MINIMUM)
C                  = 6 INCREASING SPACING IN ETA(I) DIRECTION (MINIMUM)
C                  = 7 DOUBLE STRETCHING (MINIMUM SPACING)
C                  = 8 ORIGINAL DECREASING STRETCHING FUNCTION
C                  = 9 ORIGINAL INCREASING STRETCHING FUNCTION
C                  =10 USER INPUT STRETCHING FUNCTION
C----------------------------------------------------------------------
      WRITE(NU6,1100) ITITLE,IZONE
C----------------------------------------------------------------------
C     READ INPUT PARAMETERS
C----------------------------------------------------------------------
  100 IF(MAPTEN.EQ.0) THEN
C
                      READ(NU5,1000)  MAPEDGE
C
                      END IF
C
                      READ(NU5,1000) MAPSIDE
                      READ(NU5,1000) MARCH
C
      IF(MARCH.LT.1 .OR. MARCH.GT.3) MARCH = 1
C
```

```
      READ(NU5,1000) NMBRNDS,ISTRTCH
C
C---PRINT OUT INPUT VARIABLES
C
                    WRITE(NU6,3000) MAPEDGE
                    WRITE(NU6,3010) MAPSIDE
                    WRITE(NU6,3020) MARCH
C
                    WRITE(NU6,3040) NMBRNDS,ISTRTCH
C
C---INITIALIZE FLAGS TO CHECK IF POINT, EDGE, OR SURFACE HAS BEEN INPUT
C
      DO 130 I=1,8
  130 IFLAGP(I) = 0
C
      DO 140 I=1,12
  140 IFLAGE(I) = 0
C
      DO 150 I=1,6
  150 IFLAGS(I) = 0
C
C---SET ORDER OF EXECUTION
C
      INDEX(1) = MARCH
      INDEX(3) = 3
C
      DO 160 I=2,3
         INDEX(I) = INDEX(I-1) + 1
  160 IF(INDEX(I).GT.3) INDEX(I) = 1
C
C---INITIALIZE ETA
C
      ETA(1) = 0.0
      ETA(2) = 0.0
      ETA(3) = 0.0
C
C-------------------------------------------------------------------
C     READ STRETCHING PARAMETERS
C-------------------------------------------------------------------
C
  300 DO 310 I=1,3
C
      STRETCH(I) = 0.0
C
      IF(ISTRTCH(I).LE.1) GO TO 310
C
      READ(NU5,1020) STRETCH
C
      GO TO 320
C
  310 CONTINUE
C-----------------------------------------------------------------------
C     COMPUTE STRETCHING FUNCTION PARAMETER B USING NEWTON-RAPHSON
C-----------------------------------------------------------------------
  320 DO 370 I=1,3
C
         B = STRETCH(I)
        DS = B
      TNODE = REAL(NMBRNDS(I))
C
```

```
C---DECREASING OR INCREASING SPACING (INPUT MINIMUM SPACING)
C
      IF(ISTRTCH(I).EQ.5 .OR. ISTRTCH(I).EQ.6) THEN
C
                          B = SQRT(1.0 - (TNODE - 1.0)*DS)/(TNODE - 1.0)
C
                          DO 330 ITER=1,10
C
                            ARG1 = B*(TNODE - 1.)
                            ARG2 = B*(TNODE - 2.)
C
                           EXPA1 = EXP(ARG1)
                           EXPA2 = EXP(ARG2)
C
                           TANH1 = (EXPA1 - 1./EXPA1)/(EXPA1 + 1./EXPA1)
                           TANH2 = (EXPA2 - 1./EXPA2)/(EXPA2 + 1./EXPA2)
C
                             PSI = DS - (1.0 - TANH2/TANH1)
C
                          TANHP1 = 1.0 - TANH1**2
                          TANHP2 = 1.0 - TANH2**2
C
                            PSIP =   (1.0/TANH1)*(TANHP2*(TNODE - 2.)
     &                                - (TANH2/TANH1)* TANHP1*(TNODE - 1.))
C
                          IF(PSIP.EQ.0.) THEN
C
                                         WRITE(NU6,5100)
C
                                         STOP
C
                                         END IF
C
                              B0 = B
                               B = B0 - PSI/PSIP
                             DBF = (B - B0)/B0
C
                          WRITE(NU6,5200) I,PSI,PSIP,B,DBF
C
  330                     IF(ABS(DBF).LE.0.001) GO TO 340
C
  340                                          END IF
C
C---DOUBLE STRETCHING (INPUT MINIMUM SPACING)
C
      IF(ISTRTCH(I).EQ.7) THEN
C
                          B = SQRT(1.0 - (TNODE - 1.0)*DS)/(TNODE - 1.0)
C
                          DO 350 ITER=1,10
C
                            ARG1 = B*(TNODE - 1.)
                            ARG3 = B*(TNODE - 3.)
C
                           EXPA1 = EXP(ARG1)
                           EXPA3 = EXP(ARG3)
C
                           TANH1 = (EXPA1 - 1./EXPA1)/(EXPA1 + 1./EXPA1)
                           TANH3 = (EXPA3 - 1./EXPA3)/(EXPA3 + 1./EXPA3)
C
```

```
                              PSI = DS - 0.5*(1.0 - TANH3/TANH1)
C
                           TANHP1 = 1.0 - TANH1**2
                           TANHP3 = 1.0 - TANH3**2
C
                             PSIP =   (0.5/TANH1)*(TANHP3*(TNODE - 3.0)
     &                                - (TANH3/TANH1)* TANHP1*(TNODE - 1.0))
C
                           IF(PSIP.EQ.0.) THEN
C
                                         WRITE(NU6,5000)
C
                                         STOP
C
                                         END IF
C
                                B0 = B
                                 B = B0 - PSI/PSIP
                               DBF = (B - B0)/B0
C
                           WRITE(NU6,5200) I,PSI,PSIP,B,DBF
C
  350                      IF(ABS(DBF).LE.0.001) GO TO 360
C
  360                      END IF
C
  370 STRETCH(I) = B
C
C
C---WRITE STRETCHING PARAMETERS
C
      DO 390 I=1,3
C
      IF(ISTRTCH(I).LE.1) GO TO 390
C
                   WRITE(NU6,3050) STRETCH
C
                   GO TO 400
  390 CONTINUE
C-----------------------------------------------------------------------
C   READ INPUT PARAMETERS FOR ARBITRARY GRID SPACING (ETAS)
C-----------------------------------------------------------------------
  400 DO 410 I=1,3
C
      IF(ISTRTCH(I).NE.1)              GO TO 410
      IF(ISECT.GT.1 .AND. I.NE.MARCH) GO TO 410
C
      READ(NU5,1020)    (ETAS(I,J),J=1,NMBRNDS(I))
      WRITE(NU6,1110) I,(ETAS(I,J),J=1,NMBRNDS(I))
C
  410 CONTINUE
C-----------------------------------------------------------------------
C   HGM TWO DUCT INPUT DATA
C-----------------------------------------------------------------------
      CALL HGMIN
C-----------------------------------------------------------------------
C   INPUT PARAMETERS FOR EDGE COEFFICIENTS
C-----------------------------------------------------------------------
      WRITE(NU6,1100) ITITLE,IZONE
      WRITE(NU6,2040)
```

```
C
              LINE = 6
                II = 0
C
C---TOTAL NUMBER OF EDGES
C
            NEDGES = 8*3 - 12
C
      DO 540 I=1,NEDGES
C
C      IF(IFLAGE(I).EQ.1) GO TO 540
C
            ITOTAL = 1
               MAP = MAPEDGE(I)
C
C---DETERMINE THE NUMBER OF SEGMENTS ON AN EDGE
C
      DO 500 J=1,10
C
        NMBRSEG(I) = J
               MAP = MAP/10
C
      IF(MAP.EQ.0) GO TO 510
C
  500       ITOTAL = ITOTAL*10
C
  510          MAP = MAPEDGE(I)
C
      DO 530 J=1,NMBRSEG(I)
C
C---DETERMINE THE MAPPING FOR EACH SEGMENT
C
       MAPSEG(J,I) = MAP/ITOTAL
               MAP = MAP - MAPSEG(J,I)*ITOTAL
C
C---EDGE COEFFICIENTS FOR EACH SEGMENT
C
      IF(MAPSEG(J,I).LE.1) GO TO 530
C
      IF(I.NE.II) THEN
C
                  LINE = LINE + 2
C
                  IF(LINE.GE.60) THEN
C
                                WRITE(NU6,1100) ITITLE,IZONE
                                WRITE(NU6,2040)
C
                                LINE = 8
C
                                 END IF
C
                  WRITE(NU6,2050) I,J,(COEFE(K,J,I),K=1,8)
C
                  ELSE
C
                  LINE = LINE + 2
C
                  IF(LINE.GE.60) THEN
C
```

```
                           WRITE(NU6,1100) ITITLE,IZONE
                           WRITE(NU6,2040)
C
                           LINE = 8
C
                            END IF
C
                 WRITE(NU6,2060) J,(COEFE(K,J,I),K=1,8)
C
                 END IF
C
            II = I
C
  530    ITOTAL = ITOTAL/10
C
  540 CONTINUE
C-----------------------------------------------------------------------
C   INPUT PARAMETERS FOR SURFACE COEFFFICIENTS
C-----------------------------------------------------------------------
C
                      LINE = LINE + 5
C
                   IF(LINE.GE.60) THEN
C
                           WRITE(NU6,1100) ITITLE,IZONE
C
                           LINE = 6
C
                              END IF
C
                   WRITE(NU6,3060)
C
      DO 610 I=1,6
C
C      IF(IFLAGS(I).EQ.1) GO TO 610
C
      IF(MAPSIDE(I).LE.2) GO TO 610
C
                   LINE = LINE + 2
C
                IF(LINE.GE.60) THEN
C
                           WRITE(NU6,1100) ITITLE,IZONE
                           WRITE(NU6,3060)
C
                           LINE = 8
C
                           END IF
C
      WRITE(NU6,3065) I,(COEFS(J,I),J=1,8)
C
  610 CONTINUE
C-----------------------------------------------------------------------
C   INPUT DATA FOR CORNER POINTS AND SEGMENT END POINTS
C-----------------------------------------------------------------------
                   LINE = LINE + 5
C
                IF(LINE.GE.60) THEN
C
                           WRITE(NU6,1100) ITITLE,IZONE
```

```
C
                              LINE = 6
C
                              END IF
C
      WRITE(NU6,3070)
C
      DO 750 I=1,NEDGES
C
      IF(I.GT.8)         GO TO 700
C
C--- CORNER POINTS
C
         LINE = LINE + 2
C
      IF(LINE.GE.60) THEN
C
                              WRITE(NU6,1100) ITITLE,IZONE
                              WRITE(NU6,3070)
C
                    LINE = 8
C
                    END IF
C
                WRITE(NU6,3080) I,(POINT(J,I),J=1,3)
C
C
  700 IF(NMBRSEG(I).EQ.1) GO TO 750
C
C--- SEGMENT MAXIMUMS
C
      DO 740 J=1,NMBRSEG(I) - 1
C
         LINE = LINE + 2
C
      IF(LINE.GE.60) THEN
C
                              WRITE(NU6,1100) ITITLE,IZONE
                              WRITE(NU6,3070)
C
                    LINE = 8
C
                    END IF
C
                   IF(IFLAGE(I).EQ.1) ETAMAX(J,I) =
     &             ETAMAX(J,I)*(NMBRNDS(N) - 1.0) + 1.0
C
                   WRITE(NU6,3090)I,J,(SEGMAX(K,J,I),K=1,5),ETAMAX(J,I)
C
                   DO 720 N=1,3
                   DO 720 L=1,4
C
  720              IF(IRAY(L,N).EQ.I) GO TO 730
C
  730              CONTINUE
C
C---CONVERT NODE NUMBER TO ETA VALUE
C
             ETAMAX(J,I) = (ETAMAX(J,I) - 1.0)/(NMBRNDS(N) - 1.0)
C
```

```
  740 CONTINUE
  750 CONTINUE
C
      DO 930 I=1,3
C
      DETA(I) = 1.0/(NMBRNDS(I) - 1.0)
C
                          FACTOR = NMBRNDS(I)*10.0
      IF(ISTRTCH(I).GT.0) FACTOR = NMBRNDS(I)*20.0
C
      DO 920 J=1,NRAY
C
            L = IRAY(J,I)
C
C---COMPARE X, Y, AND Z BETWEEN END POINTS OF AN EDGE
C
      DO 920 K=1,3
C
        DELTA = ABS(POINT(K,IPT1(L)) - POINT(K,IPT2(L)))/FACTOR
C
      IF(DELTA.LE.0.0)    GO TO 920
C
      IF(DELTA.LT.TOL(K)) TOL(K) = DELTA
C
  920 CONTINUE
  930 CONTINUE
C-----------------------------------------------------------------------
C     PRINT TITLE
C-----------------------------------------------------------------------
      WRITE(NU6,1100) ITITLE,IZONE
C
                     LINE = 1
C
                     WRITE(NU6,1140)
C
                     LINE = 3
C
      RETURN
C
C---FORMAT STATEMENTS
C
 1000 FORMAT(16I5)
 1010 FORMAT(6I10)
 1020 FORMAT(8E10.0)
 1030 FORMAT((4I10))
C
 1100 FORMAT(1H1,10X,20A4,13X,6H  ZONE,I3)
 1110 FORMAT(// 11H FIXED ETA_,I1,8H VALUES: // (10(3X,F10.7)) )
 1140 FORMAT( / 44H   NODE       X              Y              Z  )
C
 2000 FORMAT(// 32H EDGE SHAPE FUNCTION INDICATORS:
     &      // 40H    EDGE_1    EDGE_2    EDGE_3    EDGE_4 / 4I10 )
 2010 FORMAT(// 26H BOUNDARY CONDITION FLAGS:
     1      // 40H    EDGE_1    EDGE_2    EDGE_3    EDGE_4 / 4I10
     2     /// 26H MARCHING DIRECTION = ETA_,I1)
 2020 FORMAT(// 17H NUMBER OF NODES:
     1      // 20H     ETA_1     ETA_2 / 2I10
     2      // 22H STRETCHING FUNCTIONS:
     3      // 20H     ETA_1     ETA_2 / 2I10 )
 2030 FORMAT(// 32H STRETCHING FUNCTION PARAMETERS:
```

```
     &        // 30H          ETA_1          ETA_2 / 2(2X,F13.7) )
 2040 FORMAT(// 25H EDGE SHAPE COEFFICIENTS:
     1        // 42H EDGE  SEGMENT       COEFF_1       COEFF_2,
     2           42H       COEFF_3       COEFF_4       COEFF_5,
     3           42H       COEFF_6       COEFF_7       COEFF_8 )
 2050 FORMAT(/   2X,I2,6X,I1,3X,8(1X,F13.7))
 2060 FORMAT(/       10X,I1,3X,8(1X,F13.7))
 2080 FORMAT(/   7H POINT ,I2,1H:,12X,2(7X,F13.7),9X,F7.2)
 2090 FORMAT(/   7H  EDGE ,I2,1H:,7X,I3,2X,2(7X,F13.7),9X,F7.2,9X,F9.2)
C
 3000 FORMAT(// 32H EDGE SHAPE FUNCTION INDICATORS:
     1        // 40H    EDGE_1     EDGE_2     EDGE_3     EDGE_4,
     2           40H    EDGE_5     EDGE_6     EDGE_7     EDGE_8,
     3           40H    EDGE_9    EDGE_10    EDGE_11    EDGE_12  / 12I10 )
 3010 FORMAT(// 35H SURFACE SHAPE FUNCTION INDICATORS:
     1        // 45H      SURFACE_1      SURFACE_2      SURFACE_3,
     2           45H      SURFACE_4      SURFACE_5      SURFACE_6
     3         /          6(10X,I5))
 3020 FORMAT(// 26H MARCHING DIRECTION = ETA_,I1)
 3040 FORMAT(// 17H NUMBER OF NODES:
     1        // 30H     ETA_1      ETA_2     ETA_3 / 3I10
     2        // 22H STRETCHING FUNCTIONS:
     3        // 30H     ETA_1      ETA_2     ETA_3 / 3I10 )
 3050 FORMAT(// 32H STRETCHING FUNCTION PARAMETERS:
     1        // 45H          ETA_1          ETA_2          ETA_3
     2         /         3(2X,F13.7) )
 3060 FORMAT(// 28H SURFACE SHAPE COEFFICIENTS:
     1        // 42H SURFACE             COEFF_1       COEFF_2,
     2           42H       COEFF_3       COEFF_4       COEFF_5,
     3           42H       COEFF_6       COEFF_7       COEFF_8 )
 3065 FORMAT( /  4X,I1,9X,8(1X,F13.7))
 3070 FORMAT(// 29H COORDINATES AND ETAMAXES:
     1        // 10X,39H SEGMENT            X                  Y,
     2           41H                  Z              ETAMAX    )
 3080 FORMAT(/   7H POINT ,I2,1H:,8X,3(6X,F13.7),2(8X,F7.2))
 3090 FORMAT(/   7H  EDGE ,I2,1H:,3X,I3,2X,3(6X,F13.7),2(8X,F7.2)
     &                                                  ,7X,F9.2)
C
 5000 FORMAT(1H0,43H SINGULARITY IN TWO-END STRETCHING FUNCTION,
     &           10H PARAMETER)
 5100 FORMAT(1H0,43H SINGULARITY IN ONE-END STRETCHING FUNCTION,
     &           10H PARAMETER)
 5200 FORMAT(1H0,4H I =,I2,7H  PSI =,E12.4,8H  PSIP =,E12.4,
     &           5H  B =,E12.4,7H  DBF =,E12.4)
C
      END
C
C***********************************************************************
C*****MAPPING***********************************************************
C***********************************************************************
C
      SUBROUTINE MESH
C-----------------------------------------------------------------------
C   MESH CONTROLS THE GENERATION OF THE SPATIAL COORDINATES OF EACH NODE
C   IN THE MESH.
C-----------------------------------------------------------------------
C
      COMMON /COUNTER/ NODESAV,NODETOT,NBNODES,NPLANE
      COMMON /HEADER/  ITITLE(20),LINE
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
```

```
      COMMON /INITB/   IBOX(4,6),IRAY(4,3),NRAY,IPT1(12),IPT2(12)
      COMMON /INPUTA/  EDGE(3,12),POINT(3,8),SIDE(3,6)
      COMMON /INPUTBC/ INODEBC(3),ISIDE(3)
      COMMON /MAPING/  MAPSIDE(6),MAPSEG(10,12)
      COMMON /MARCHS/  MARCH,INDEX(3)
      COMMON /NODNMBR/ NODENUM(4000),TOL(3)
      COMMON /OUT/     NODE(3,4000)
      COMMON /PARTIAL/ DEDN(3,12),DSDN(3,2),SNORMAL(3,6)
      COMMON /SPACING/ ISTRTCH(3),STRETCH(3),ETAS(3,200),ETA(3),DETA(3)
      COMMON /UNITS/   NU5,NU6,NU20
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
C
      DIMENSION E(26)
      DIMENSION IFACE1(3,3),IFACE2(3,3),ISIDES(6)
      DIMENSION TANGENT(3),VECTOR(3),DIRECT(3)
C
      DATA IFACE1 /0,1,2,1,0,5,2,5,0/
      DATA IFACE2 /0,3,4,3,0,6,4,6,0/
      DATA ISIDES /3,4,1,2,6,5/
C
        INIT = 1
C
        FOLD = 0
C
C---DETERMINE SURFACES
C
      ISIDE1 = IFACE1(MARCH,INDEX(2))
      ISIDE2 = IFACE2(MARCH,INDEX(2))
      ISIDE3 = IFACE1(MARCH,INDEX(3))
      ISIDE4 = IFACE2(MARCH,INDEX(3))
      ISIDE5 = IFACE1(INDEX(2),INDEX(3))
      ISIDE6 = IFACE2(INDEX(2),INDEX(3))
C
C---MAXIMUM NUMBER OF NODES IN A PLANE
C
         MAXPL = NMBRNDS(INDEX(2))*NMBRNDS(INDEX(3))
C
      INDEX(1) = MARCH
C----------------------------------------------------------------------
C   AXIS
C----------------------------------------------------------------------
      DO 700 IAXIS=1,NMBRNDS(INDEX(1))
C
      IF(IAXIS.EQ.1 .AND. ISECT.GT.1) GO TO 700
C
C---SEPERATE BOUNDARY CONDITIONS AND DETERMINE ETA
C
      CALL ETABC(MARCH,INDEX(1),IAXIS)
C
C---CALCULATE COORDINATES AND DERIVATIVES FOR POINTS ON EDGES
C
      CALL EDGES(INIT,INDEX(1),ETA(INDEX(1)),FOLD)
C
C---NUMBER OF NODES TO BE STORED
C
      NODSTOR = NODESAV
C
C----------------------------------------------------------------------
C   ROW
C----------------------------------------------------------------------
```

```
      DO 500 JAXIS=1,NMBRNDS(INDEX(2))
C
C---SEPERATE BOUNDARY CONDITIONS AND DETERMINE ETA
C
      CALL ETABC(MARCH,INDEX(2),JAXIS)
C
C---CALCULATE COORDINATES AND DERIVATIVES FOR POINTS ON EDGES
C
      CALL EDGES(INIT,INDEX(2),ETA(INDEX(2)),FOLD)
C
C---CALCULATE COORDINATES AND SURFACE NORMAL FOR POINTS ON SURFACES-----
C
      CALL SURFACE(INIT,ISIDE1)
C
      CALL SURFACE(INIT,ISIDE2)
C----------------------------------------------------------------------
C   COLUMN
C----------------------------------------------------------------------
      DO 400 KAXIS=1,NMBRNDS(INDEX(3))
C
C---SEPERATE BOUNDARY CONDITIONS AND DETERMINE ETA
C
      CALL ETABC(MARCH,INDEX(3),KAXIS)
C
C---CALCULATE COORDINATES AND DERIVATIVES FOR POINTS ON EDGES
C
      CALL EDGES(INIT,INDEX(3),ETA(INDEX(3)),FOLD)
C
C---CALCULATE COORDINATES AND SURFACE NORMAL FOR POINTS ON SURFACES
C
      CALL SURFACE(INIT,ISIDE3)
C
      CALL SURFACE(INIT,ISIDE4)
C
      CALL SURFACE(INIT,ISIDE5)
C
      CALL SURFACE(INIT,ISIDE6)
C
C---ETA COEFFICIENTS FOR TRI-LINEAR INTERPOLATION
C
                  E(1)  = 1.0 - ETA(3)
                  E(2)  =       ETA(3)
                  E(3)  = 1.0 - ETA(2)
                  E(4)  =       ETA(2)
                  E(5)  = 1.0 - ETA(1)
                  E(6)  =       ETA(1)
                  E(7)  =   E(5)*E(3)
                  E(8)  =   E(5)*ETA(2)
                  E(9)  = ETA(1)*E(3)
                  E(10) = ETA(1)*ETA(2)
                  E(11) =   E(5)*E(1)
                  E(12) =   E(5)*ETA(3)
                  E(13) = ETA(1)*E(1)
                  E(14) = ETA(1)*ETA(3)
                  E(15) =   E(3)*E(1)
                  E(16) =   E(3)*ETA(3)
                  E(17) = ETA(2)*E(1)
                  E(18) = ETA(2)*ETA(3)
                  E(19) =   E(5)*E(3)  *E(1)
                  E(20) =   E(5)*E(3)  *ETA(3)
```

```
                E(21) =   E(5)*ETA(2)*E(1)
                E(22) =   E(5)*ETA(2)*ETA(3)
                E(23) = ETA(1)*E(3)   *E(1)
                E(24) = ETA(1)*E(3)   *ETA(3)
                E(25) = ETA(1)*ETA(2)*E(1)
                E(26) = ETA(1)*ETA(2)*ETA(3)
C
C---INCREMENT NODE COUNTERS
C
                 INIT = 0
C
              NODESAV = NODESAV + 1
               NODNUM = NODESAV + NODETOT
C
C---CALCULATE THE COORDINATES
C
      DO 340 L=1,3
  340   NODE(L,NODESAV) = E(1)*SIDE(L,1) + E(2)*SIDE(L,3)
     1                  + E(3)*SIDE(L,2) + E(4)*SIDE(L,4)
     2                  + E(5)*SIDE(L,5) + E(6)*SIDE(L,6)
     3-E( 7)*EDGE(L,5)-E( 8)*EDGE(L, 8)-E( 9)*EDGE(L,6)-E(10)*EDGE(L, 7)
     4-E(11)*EDGE(L,4)-E(12)*EDGE(L,12)-E(13)*EDGE(L,2)-E(14)*EDGE(L,10)
     5-E(15)*EDGE(L,1)-E(16)*EDGE(L, 9)-E(17)*EDGE(L,3)-E(18)*EDGE(L,11)
     6                  + E(19)*POINT(L,1) + E(20)*POINT(L,5)
     7                  + E(21)*POINT(L,4) + E(22)*POINT(L,8)
     8                  + E(23)*POINT(L,2) + E(24)*POINT(L,6)
     9                  + E(25)*POINT(L,3) + E(26)*POINT(L,7)
C
  350 CONTINUE
C
  400 CONTINUE
  500 CONTINUE
C-----------------------------------------------------------------------
C   PLANE OUTPUT
C-----------------------------------------------------------------------
      IF(IAXIS.EQ.1) GO TO 700
C
C---PRINT AND STORE DATA------------------------------------------------
C
      IF(NODSTOR.NE.0) THEN
C
                        CALL OUTPUT(NU20,NODSTOR)
C
C---TRANSFER DATA SECOND PLANE TO FIRST PLANE
C
                        DO 630 I=1,NODESAV
C
                        DO 600 J=1,5
  600                      NODE(J,I) = NODE(J,I + NODSTOR)
C
  630                   CONTINUE
C
                        END IF
C
C---TRANSFER NODE NUMBERS FROM SECOND PLANE TO FIRST PLANE--------------
C
      DO 650 L=1,MAXPL
  650                NODENUM(L) = NODENUM(L + MAXPL)
C
  700 CONTINUE
```

```
C-----------------------------------------------------------------------
C       OUTPUT
C-----------------------------------------------------------------------
C
C---PRINT AND STORE DATA
                           NODSTOR = NODESAV
C
      IF(NODESAV.NE.0) CALL OUTPUT(NU20,NODSTOR)
C
                           NODESAV = 0
C
      RETURN
C
C---FORMAT STATEMENTS
C
 1100 FORMAT(1H1,10X,20A4,13X,8H SECTION,I2,3H OF,I3,9H FOR ZONE,I3)
C
 1110 FORMAT(   8H  NODE =,I10
     1       / 41X,2H X,13X,2H Y,12X,2H Z
     2       / 8H E( 1) =,F13.7,15H      SIDE(1) =,6(1X,F13.7)
     3       / 8H E( 3) =,F13.7,15H      SIDE(2) =,6(1X,F13.7)
     4       / 8H E( 2) =,F13.7,15H      SIDE(3) =,6(1X,F13.7)
     5       / 8H E( 4) =,F13.7,15H      SIDE(4) =,6(1X,F13.7)
     6       / 8H E( 5) =,F13.7,15H      SIDE(5) =,6(1X,F13.7)
     7       / 8H E( 6) =,F13.7,15H      SIDE(6) =,6(1X,F13.7))
C
 1120 FORMAT(   8H E(15) =,F13.7,15H     EDGE( 1) =,6(1X,F13.7)
     1       / 8H E(13) =,F13.7,15H     EDGE( 2) =,6(1X,F13.7)
     2       / 8H E(17) =,F13.7,15H     EDGE( 3) =,6(1X,F13.7)
     3       / 8H E(11) =,F13.7,15H     EDGE( 4) =,6(1X,F13.7)
     4       / 8H E( 7) =,F13.7,15H     EDGE( 5) =,6(1X,F13.7)
     5       / 8H E( 9) =,F13.7,15H     EDGE( 6) =,6(1X,F13.7))
C
 1130 FORMAT(   8H E(10) =,F13.7,15H     EDGE( 7) =,6(1X,F13.7)
     1       / 8H E( 8) =,F13.7,15H     EDGE( 8) =,6(1X,F13.7)
     2       / 8H E(16) =,F13.7,15H     EDGE( 9) =,6(1X,F13.7)
     3       / 8H E(14) =,F13.7,15H     EDGE(10) =,6(1X,F13.7)
     4       / 8H E(18) =,F13.7,15H     EDGE(11) =,6(1X,F13.7)
     5       / 8H E(12) =,F13.7,15H     EDGE(12) =,6(1X,F13.7))
C
 1140 FORMAT(   8H E(19) =,F13.7,15H     POINT(1) =,6(1X,F13.7)
     1       / 8H E(23) =,F13.7,15H     POINT(2) =,6(1X,F13.7)
     2       / 8H E(25) =,F13.7,15H     POINT(3) =,6(1X,F13.7)
     3       / 8H E(21) =,F13.7,15H     POINT(4) =,6(1X,F13.7)
     4       / 8H E(20) =,F13.7,15H     POINT(5) =,6(1X,F13.7)
     5       / 8H E(24) =,F13.7,15H     POINT(6) =,6(1X,F13.7)
     6       / 8H E(26) =,F13.7,15H     POINT(7) =,6(1X,F13.7)
     7       / 8H E(22) =,F13.7,15H     POINT(8) =,6(1X,F13.7))
C
      END
C
C***********************************************************************
C*****MAPPING***********************************************************
C***********************************************************************
C
      SUBROUTINE EDGES(INIT,IDIR,ETA,FOLD)
C-----------------------------------------------------------------------
C   INTERPOLATES ALONG EACH EDGE OF EACH SIDE OF ZONE AS PART OF THE
C   BI/TRI-LINEAR INTERPOLATION SCHEME
C-----------------------------------------------------------------------
```

```
      COMMON /COEFF/   COEFE(8,10,12),COEFS(8,6),NMBRSEG(12)
      COMMON /COUNTER/ NODESAV,NODETOT,NBNODES,NPLANE
      COMMON /HEADER/  ITITLE(20),LINE
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /INITB/   IBOX(4,6),IRAY(4,3),NRAY,IPT1(12),IPT2(12)
      COMMON /INPUTA/  EDGE(3,12),POINT(3,8),SIDE(3,6)
      COMMON /MAPED/   KSEG(12),UAXIS(3,6),IEDGE1(6),IEDGE2(6),GAMMA
      COMMON /MAXIMUM/ ETAMAX(10,12),SEGMAX(3,10,12)
      COMMON /PARTIAL/ DEDN(3,12),DSDN(3,2),SNORMAL(3,6)
      COMMON /SEGMENT/ PT1(6,10,12),PT2(6,10,12),ETA1(10,12),ETA2(10,12)
      COMMON /UNITS/   NU5,NU6,NU20
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
C-----------------------------------------------------------------------
C   INTERMEDIATE PRINT
C-----------------------------------------------------------------------
      NODNUM = NODESAV + NODETOT + 1
C
C-----------------------------------------------------------------------
C   CALCULATE EDGE COORDINATES AND DERIVATIVE
C-----------------------------------------------------------------------
   20 DO 200 I=1,NRAY
C
C---DETERMINE WHICH EDGE
C
           IEDGE = IRAY(I,IDIR)
C
C---EDGE INITIALIZATION
C
      IF(INIT.EQ.1) CALL EMAPI(IEDGE,FOLD,IDIR,I)
C
C---DETERMINE WHICH SEGMENT
C
      DO 100 JSEG=1,NMBRSEG(IEDGE)
C
              ISEG = JSEG
C
  100 IF(ETA.GE.ETA1(JSEG,IEDGE) .AND. ETA.LE.ETA2(JSEG,IEDGE)) GOTO 110
C
  110 KSEG(IEDGE) = ISEG
C
C---DETERMINE WHERE ALONG THE SEGMENT
C
                         DENOM = ETA2(ISEG,IEDGE) - ETA1(ISEG,IEDGE)
      IF(DENOM.EQ.0.0) DENOM = 1.0
C
                         RATIO = (ETA - ETA1(ISEG,IEDGE))/DENOM
C
C---CALCULATE THE COORDINATES AND DERIVATIVE
C
      CALL EMAP(IEDGE,ISEG,RATIO,EDGE(1,IEDGE),DEDN(1,IEDGE))
C
C-----------------------------------------------------------------------
C   INTERMEDIATE PRINT
C-----------------------------------------------------------------------
C
  200 CONTINUE
C
      RETURN
C
C---FORMAT STATEMENTS
```

```
C
 1100 FORMAT(1H1,10X,20A4,13X,8H SECTION,I2,3H OF,I3,9H FOR ZONE,I3)
 1110 FORMAT(/ 41H    NODE   EDGE           X               Y,
     1        43H                  Z            TANGENT:     THETA,
     2        36H        PHI       ETA     RATIO    ETAMAX)
 1120 FORMAT(1X,I6,4X,I2,3X,3(3X,F13.7),11X,2(2X,F7.2),3(2X,F7.5))
C
      END
C
C**********************************************************************
C*****MAPPING**********************************************************
C**********************************************************************
C
      SUBROUTINE EMAPI(IEDGE,FOLD,IDIR,NMBREDG)
C----------------------------------------------------------------------
C   EDGE MAPPING INITIALIZATION
C----------------------------------------------------------------------
      COMMON /COEFF/   COEFE(8,10,12),COEFS(8,6),NMBRSEG(12)
      COMMON /COUNTER/ NODESAV,NODETOT,NBNODES,NPLANE
      COMMON /EDGE0/   UI(3,10,12),UJ(3,10,12),UK(3,10,12),
     &                 R1(3,10,12),R2(3,10,12),THETA(10,12)
      COMMON /EDGE3/   ARC(10,12),ARC1(10,12),XLENGTH(10,12),
     &                 RA(10,12),RC(10,12),RE(10,12),THETA1(10,12)
      COMMON /EDGE8/   RM1(10,12),RM2(10,12),RPA1(10,12),RPA2(10,12)
      COMMON /HEADER/  ITITLE(20),LINE
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /INITB/   IBOX(4,6),IRAY(4,3),NRAY,IPT1(12),IPT2(12)
      COMMON /INITC/   PI,RADDEG
      COMMON /INPUTA/  EDGE(3,12),POINT(3,8),SIDE(3,6)
      COMMON /MAPED/   KSEG(12),UAXIS(3,6),IEDGE1(6),IEDGE2(6),GAMMA
      COMMON /MAPING/  MAPSIDE(6),MAPSEG(10,12)
      COMMON /MARCHS/  MARCH,INDEX(3)
      COMMON /MAXIMUM/ ETAMAX(10,12),SEGMAX(3,10,12)
      COMMON /PARTIAL/ DEDN(3,12),DSDN(3,2),SNORMAL(3,6)
      COMMON /SEGMENT/ PT1(6,10,12),PT2(6,10,12),ETA1(10,12),ETA2(10,12)
C
      DIMENSION ETAMX(10,12),VECTER(3)
C
C---INITIALIZE
C
      KSEG(IEDGE) = 1
C
      DO 10 N=1,NMBRSEG(IEDGE)
   10 ETAMX(N,IEDGE) = ETAMAX(N,IEDGE)
C
   40  ETAMX(NMBRSEG(IEDGE),IEDGE) = 1.0
C
                    ETA1(1,IEDGE) = 0.0
      ETAMAX(NMBRSEG(IEDGE),IEDGE) = 1.0
C----------------------------------------------------------------------
C   INITIALIZE SEGMENTS
C----------------------------------------------------------------------
      DO 1000 ISEG=1,NMBRSEG(IEDGE)
C
C---DETERMINE THE COORDINATES AT THE END POINTS
C
      IF(ISEG.EQ.1) THEN
C
      DO 50 J=1,3
                 PT1(J,   1,IEDGE) = POINT(J,IPT1(IEDGE))
```

```
      SEGMAX(J,NMBRSEG(IEDGE),IEDGE) = POINT(J,IPT2(IEDGE))
   50              PT2(J,ISEG,IEDGE) = SEGMAX(J,ISEG,IEDGE)
C
                    ELSE
C
      DO 60 J=1,3
                   PT1(J,ISEG,IEDGE) = SEGMAX(J,(ISEG-1),IEDGE)
   60              PT2(J,ISEG,IEDGE) = SEGMAX(J,ISEG,IEDGE)
C
                    END IF
C
C---ETA VALUE AT THE END OF EACH SEGMENT
C
      IF(ISEG.GT.1) ETA1(ISEG,IEDGE) = ETA2(ISEG-1,IEDGE)
                    ETA2(ISEG,IEDGE) = ETAMX(ISEG,IEDGE)
C
C---VECTORS FROM ORIGIN TO END POINTS
C
      DO 80 J=1,3
      R1(J,ISEG,IEDGE) = PT1(J,ISEG,IEDGE) - COEFE(J,ISEG,IEDGE)
   80 R2(J,ISEG,IEDGE) = PT2(J,ISEG,IEDGE) - COEFE(J,ISEG,IEDGE)
C
      CALL VMAG(R1(1,ISEG,IEDGE),RMAG1)
C
      CALL VMAG(R2(1,ISEG,IEDGE),RMAG2)
C-----------------------------------------------------------------------
C   CHOOSE MAPPING FUNCTION
C-----------------------------------------------------------------------
                          MAP = MAPSEG(ISEG,IEDGE)

      GO TO (1000,200,300,400,500,600,700) MAP
C-----------------------------------------------------------------------
C   CIRCULAR ARC                                                 MAP = 2
C-----------------------------------------------------------------------
C---SWEEP ANGLE
C
  200 CALL VDOT(R1(1,ISEG,IEDGE),R2(1,ISEG,IEDGE),R1DOTR2)
C
                          ARG = R1DOTR2/(RMAG1*RMAG2)
C
      IF(ABS(ARG).GT.1.0) ARG = ARG/ABS(ARG)
C
            THETA(ISEG,IEDGE) = ACOS(ARG)
C
      GO TO 1000
C-----------------------------------------------------------------------
C   CONICS                                                       MAP = 3
C-----------------------------------------------------------------------
C---PROJECTION ONTO CONIC AXIS
C
  300 IF(COEFE(7,ISEG,IEDGE).GT.0.0) THEN
C
                                    DO 305 I=1,3
                                                TEMP = R1(I,ISEG,IEDGE)
                                    R1(I,ISEG,IEDGE) = R2(I,ISEG,IEDGE)
  305                               R2(I,ISEG,IEDGE) = TEMP
C
                                     TEMP = RMAG1
                                    RMAG1 = RMAG2
                                    RMAG2 = TEMP
```

```
C
                                        END IF
C
      CALL VDOT(R1(1,ISEG,IEDGE),COEFE(4,ISEG,IEDGE),A1)
C
      CALL VDOT(R2(1,ISEG,IEDGE),COEFE(4,ISEG,IEDGE),A2)
C
C---RECIPROCAL OF ECCENTRICITY (RE = 1/E)
C
                                       ECT = ABS((A1-A2)/(RMAG1-RMAG2))
C
      IF(ECT.GT.0.9999.AND.ECT.LT.1.0001) ECT = 1.0
C
            RE(ISEG,IEDGE) = ECT
C
C---DISTANCE FROM DIRECTRIX TO FOCUS
C
            RC(ISEG,IEDGE) = RMAG1*RE(ISEG,IEDGE) - A1
C
C---THETA1: ANGLE BETWEEN NEGATIVE OF CONIC AXIS AND R1
C
                            ARG = A1/RMAG1
      IF(ABS(ARG).GT.1.0) ARG = ARG/ABS(ARG)
C
            THETA1(ISEG,IEDGE) = ACOS(-ARG)
C
C---THETA2: ANGLE BETWEEN NEGATIVE OF CONIC AXIS AND R2
C
                            ARG = A2/RMAG2
      IF(ABS(ARG).GT.1.0) ARG = ARG/ABS(ARG)
C
                        THETA2 = ACOS(-ARG)
C
C---SWEEP ANGLE: THETA2 - THETA1
C
             THETA(ISEG,IEDGE) = THETA2 - THETA1(ISEG,IEDGE)
C
C---LOCAL COORDINATE SYSTEM
C
      DO 310  J=1,3
              UJ(J,ISEG,IEDGE) = R1(J,ISEG,IEDGE)/RMAG1
  310         UI(J,ISEG,IEDGE) = R2(J,ISEG,IEDGE)/RMAG2
C
      CALL CROSS(UI(1,ISEG,IEDGE),UJ(1,ISEG,IEDGE),UK(1,ISEG,IEDGE),10)
C
C---INTEGRATION CONSTANTS
C
                RA(ISEG,IEDGE) = SQRT(ABS(RE(ISEG,IEDGE)**2 - 1.0))
                             T = TAN(THETA1(ISEG,IEDGE)*0.5)
C
C---ELLIPSE-----------------------------------------------------------
C
      IF(RE(ISEG,IEDGE).LT.1.0001) GO TO 320
C
C---ARC LENGTH INTEGRAL (CRC EQN. 341) EVALUATED AT THETA1
C
                           ARG = RA(ISEG,IEDGE)*T/(RE(ISEG,IEDGE) + 1.0)
      ARC1(ISEG,IEDGE) = 2.*RC(ISEG,IEDGE)*ATAN(ARG)/RA(ISEG,IEDGE)
C
C---ARC LENGTH INTEGRAL (CRC EQN. 341) EVALUATED AT THETA2
```

```
C
                         T = TAN(THETA2*0.5)
                       ARG = RA(ISEG,IEDGE)*T/(RE(ISEG,IEDGE) + 1.0)
                      ARC2 = 2.*RC(ISEG,IEDGE)*ATAN(ARG)/RA(ISEG,IEDGE)
C
C---TOTAL ARC LENGTH
C
       ARC(ISEG,IEDGE) = ARC2 - ARC1(ISEG,IEDGE)
C
C---TANGENT CONSTANT
C
      XLENGTH(ISEG,IEDGE) = ARC(ISEG,IEDGE)*(RE(ISEG,IEDGE) + 1.0)
     &                      /(THETA(ISEG,IEDGE)*RC(ISEG,IEDGE))
C
      GO TO 1000
C
C---HYPERBOLA-----------------------------------------------------------
C
  320 IF(RE(ISEG,IEDGE).GT.0.9999) GO TO 330
C
C---ARC LENGTH INTEGRAL EVALUATED AT THETA1
C
                       ARG = (RA(ISEG,IEDGE)*T + RE(ISEG,IEDGE) + 1.)
     &                      /(RA(ISEG,IEDGE)*T - RE(ISEG,IEDGE) - 1.)
                       ARG = ABS(ARG)
        ARC1(ISEG,IEDGE) = RC(ISEG,IEDGE)*LOG(ARG)/RA(ISEG,IEDGE)
C
C---ARC LENGTH INTEGRAL EVALUATED AT THETA2
C
                         T = TAN(THETA2*0.5)
                       ARG = (RA(ISEG,IEDGE)*T + RE(ISEG,IEDGE) + 1.)
     &                      /(RA(ISEG,IEDGE)*T - RE(ISEG,IEDGE) - 1.)
                       ARG = ABS(ARG)
                      ARC2 = RC(ISEG,IEDGE)*LOG(ARG)/RA(ISEG,IEDGE)
C
C---TOTAL ARC LENGTH
C
        ARC(ISEG,IEDGE) = ARC2 - ARC1(ISEG,IEDGE)
C
C---TANGENT CONSTANT
C
      XLENGTH(ISEG,IEDGE) = -4.0*(1.0 + RE(ISEG,IEDGE))
     &              *ARC(ISEG,IEDGE)/(THETA(ISEG,IEDGE)*RC(ISEG,M))
C
      GO TO 1000
C
C---PARABOLA------------------------------------------------------------
C
C---ARC LENGTH INTEGRAL EVALUATED AT THETA1
C
  330   ARC1(ISEG,IEDGE) = RC(ISEG,IEDGE)*T
C
C---ARC LENGTH INTEGRAL EVALUATED AT THETA2
C
                         T = TAN(THETA2*0.5)
C
C---TOTAL ARC LENGTH
C
        ARC(ISEG,IEDGE) = RC(ISEG,IEDGE)*T - ARC1(ISEG,IEDGE)
C
```

```
C---TANGENT CONSTANT
C
      XLENGTH(ISEG,IEDGE) = 2.0*ARC(ISEG,IEDGE)
     &                      /(THETA(ISEG,IEDGE)*RC(ISEG,IEDGE))
C
      GO TO 1000
C-----------------------------------------------------------------------
C   EDGE OF REVOLUTION                                          MAP = 4
C-----------------------------------------------------------------------
  400 CONTINUE
C
C---UK: NORMALIZED VECTOR ALONG AXIS OF REVOLUTION
C
      CALL VMAG(COEFE(4,ISEG,IEDGE),UKM)
C
      DO 410 I=1,3
C
  410 UK(I,ISEG,IEDGE) = COEFE(I + 3,ISEG,IEDGE)/UKM
C
C---UJ: NORMALIZED VECTOR FROM AXIS TOWARD EDGE
C
      CALL CROSS(UK(1,ISEG,IEDGE),R1(1,ISEG,IEDGE),UJ(1,ISEG,IEDGE),20)
C
C---UI: NORMALIZED VECTOR FROM AXIS TO FIRST POINT
C
      CALL CROSS(UJ(1,ISEG,IEDGE),UK(1,ISEG,IEDGE),UI(1,ISEG,IEDGE),21)
C
C---R1: VECTOR FROM AXIS TO FIRST POINT--------------------------------
C
      CALL VDOT(R1(1,ISEG,IEDGE),UK(1,ISEG,IEDGE),RPA1(ISEG,IEDGE))
C
      CALL VADD(1.0,R1(1,ISEG,IEDGE),-RPA1(ISEG,IEDGE),UK(1,ISEG,IEDGE),
     &             R1(1,ISEG,IEDGE),VECTER)
C
      CALL VMAG(R1(1,ISEG,IEDGE),RM1(ISEG,IEDGE))
C
C---R2: VECTOR FROM AXIS TO SECOND POINT-------------------------------
C
      CALL VDOT(R2(1,ISEG,IEDGE),UK(1,ISEG,IEDGE),RPA2(ISEG,IEDGE))
C
      CALL VADD(1.0,R2(1,ISEG,IEDGE),-RPA2(ISEG,IEDGE),UK(1,ISEG,IEDGE),
     &             R2(1,ISEG,IEDGE),VECTER)
C
      CALL VMAG(R2(1,ISEG,IEDGE),RM2(ISEG,IEDGE))
C
C---SWEEP ANGLE--------------------------------------------------------
C
      CALL VDOT(R1(1,ISEG,IEDGE),R2(1,ISEG,IEDGE),R1DOTR2)
C
                          ARG = R1DOTR2/(RM1(ISEG,IEDGE)*RM2(ISEG,IEDGE))
C
      IF(ABS(ARG).GT.1.) ARG = ARG/ABS(ARG)
C
            THETA(ISEG,IEDGE) = ACOS(ARG)
C
      GO TO 1000
C-----------------------------------------------------------------------
C   USER SUPPLIED SPECIAL EDGE INITIALIZATION                   MAP = 5
C-----------------------------------------------------------------------
  500 CONTINUE
```

```
C-----------------------------------------------------------------------
C   USER SUPPLIED SPECIAL EDGE INITIALIZATION                    MAP = 6
C-----------------------------------------------------------------------
  600 CONTINUE
C-----------------------------------------------------------------------
C   USER SUPPLIED SPECIAL EDGE INITIALIZATION                    MAP = 7
C-----------------------------------------------------------------------
  700 CONTINUE
C
 1000 CONTINUE
C
      RETURN
      END
C
C***********************************************************************
C*****MAPPING***********************************************************
C***********************************************************************
C
      SUBROUTINE EMAP(IEDGE,ISEG,RATIO,POINT,TANGENT)
C-----------------------------------------------------------------------
C   THIS ROUTINE CALCULATES THE COORDINATES,  AND TANGENT
C   OF A POINT ON AN EDGE.
C-----------------------------------------------------------------------
      COMMON /COEFF/   COEFE(8,10,12),COEFS(8,6),NMBRSEG(12)
      COMMON /EDGE0/   UI(3,10,12),UJ(3,10,12),UK(3,10,12),
     &                 R1(3,10,12),R2(3,10,12),THETA(10,12)
      COMMON /EDGE3/   ARC(10,12),ARC1(10,12),XLENGTH(10,12),
     &                 RA(10,12),RC(10,12),RE(10,12),THETA1(10,12)
      COMMON /EDGE8/   RM1(10,12),RM2(10,12),RPA1(10,12),RPA2(10,12)
      COMMON /MAPING/  MAPSIDE(6),MAPSEG(10,12)
      COMMON /SEGMENT/ PT1(6,10,12),PT2(6,10,12),ETA1(10,12),ETA2(10,12)
C
      COMMON /DFN1/    DU1(3),DU2(3),DU3(3),DFNB,DFND,DFNF
      COMMON /DFN2/    AE,BE,DFNR,ZSTAR,AGL,BETA1,BETA2,BETA3,BETA4
      COMMON /DFN3/    AD,BD,BETA(37),DELRHO(37),RADOC(37)
      COMMON /DFN5/    CE,CQ,ABOT,ATOP
C
      DIMENSION XN(3),XR(3),XP(3),VDUM(3)
C
      DIMENSION POINT(6),TANGENT(3)
      DIMENSION VECTOR(3)
C
                       MAP = MAPSEG(ISEG,IEDGE)
C
      GO TO (100,200,300,400,500,600,700) MAP
C-----------------------------------------------------------------------
C   LINEAR EDGE                                                  MAP = 1
C-----------------------------------------------------------------------
  100 DO 110 I=1,3
       POINT(I) = (1. - RATIO)*R1(I,ISEG,IEDGE) + RATIO*R2(I,ISEG,IEDGE)
C
  110 VECTOR(I) = R2(I,ISEG,IEDGE) - R1(I,ISEG,IEDGE)
C
      CALL VMAG(VECTOR,RMAG)
C
      IF(RMAG.EQ.0.0) RMAG = 1.0
C
      DO 120 I=1,3
  120 TANGENT(I) = (R2(I,ISEG,IEDGE) - R1(I,ISEG,IEDGE))/RMAG
C
```

```
      GO TO 1000
C-----------------------------------------------------------------------
C   CIRCULAR ARC                                                 MAP = 2
C-----------------------------------------------------------------------
  200        PHI1 = (1.0 - RATIO)*THETA(ISEG,IEDGE)
             PHI2 =         RATIO*THETA(ISEG,IEDGE)
C
      DO 210 I=1,3
        POINT(I) = COEFE(I,ISEG,IEDGE) +
     1         (SIN(PHI1)*R1(I,ISEG,IEDGE) + SIN(PHI2)*R2(I,ISEG,IEDGE))
     2         /SIN(THETA(ISEG,IEDGE))
C
  210 TANGENT(I) = THETA(ISEG,IEDGE)*
     1         (COS(PHI2)*R2(I,ISEG,IEDGE) - COS(PHI1)*R1(I,ISEG,IEDGE))
     2         /SIN(THETA(ISEG,IEDGE))
C
      GO TO 1000
C-----------------------------------------------------------------------
C   CONICS                                                       MAP = 3
C-----------------------------------------------------------------------
  300                               DARC =        RATIO*ARC(ISEG,IEDGE)
      IF(COEFE(7,ISEG,IEDGE).GT.0.0) DARC = (1. - RATIO)*ARC(ISEG,IEDGE)
C
C---RE = 1/E
C
      IF(RE(ISEG,IEDGE).LT.0.9999) GO TO 310
      IF(RE(ISEG,IEDGE).GT.1.0001) GO TO 320
                                   GO TO 330
C
C---HYPERBOLA-----------------------------------------------------------
C
C---CALCULATE ANGLE CORRESPONDING TO ARC LENGTH
C
  310   ARG1 = (DARC + ARC1(ISEG,IEDGE))*RA(ISEG,IEDGE)
     &         /RC(ISEG,IEDGE)
        ARG2 = (EXP(ARG1) - 1.0)*(RE(ISEG,IEDGE) + 1.0)
     &         /(RA(ISEG,IEDGE)*(EXP(ARG1) + 1.0))
       ALPHA = 2.0*ATAN(ARG2)
C
C---DERIVATIVE
C
        DEDN = XLENGTH(ISEG,IEDGE)*EXP(ARG1)
     &         /((1.0 + ARG2**2)*(1.0 - EXP(ARG1))**2)
      GO TO 340
C
C---ELLIPSE-------------------------------------------------------------
C
C---CALCULATE ANGLE CORRESPONDING TO ARC LENGTH
C
  320   ARG1 = (DARC + ARC1(ISEG,IEDGE))*RA(ISEG,IEDGE)*0.5
     &       /RC(ISEG,IEDGE)
        ARG2 = (RE(ISEG,IEDGE) + 1.0)*TAN(ARG1)/RA(ISEG,IEDGE)
       ALPHA = 2.0*ATAN(ARG2)
C
C---DERIVATIVE
C
        DEDN = XLENGTH(ISEG,IEDGE)*(1.0 + TAN(ARG1)**2)/(1. + ARG2**2)
C
      IF(COEFE(7,ISEG,IEDGE).GT.0.0) DEDN = -DEDN
C
```

```
      GO TO 340
C
C---PARABOLA-----------------------------------------------------------
C
C---CALCULATE ANGLE CORRESPONDING TO ARC LENGTH
C
  330    ARG = -(DARC + ARC1(ISEG,IEDGE))/RC(ISEG,IEDGE)
       ALPHA = 2.0*ATAN(ARG)
C
C---DERIVATIVE
C
        DEDN = XLENGTH(ISEG,IEDGE)/(1.0 + ARG**2)
C
C---------------------------------------------------------------------
C
C---MAGNITUDE OF POSITION VECTOR
C
  340      R = RC(ISEG,IEDGE)/(RE(ISEG,IEDGE) + COS(ALPHA))
C
C---RATIO USING ANGLES
C
         ESP = (ALPHA - THETA1(ISEG,IEDGE))/THETA(ISEG,IEDGE)
C
        PHI1 = (1.0 - ESP)*THETA(ISEG,IEDGE)
        PHI2 =        ESP*THETA(ISEG,IEDGE)
C
C---POSITION AND TANGENT
C
      DO 350 I=1,3
        POINT(I) = COEFE(I,ISEG,IEDGE) +
     1   R*(SIN(PHI1)*UJ(I,ISEG,IEDGE) + SIN(PHI2)*UI(I,ISEG,IEDGE))
     2  /SIN(THETA(ISEG,IEDGE))
C
      TANGENT(I) = (POINT(I) - COEFE(I,ISEG,IEDGE))
     1    *THETA(ISEG,IEDGE)*R*SIN(ALPHA)/RC(ISEG,IEDGE)
     2  + THETA(ISEG,IEDGE)*R
     3    *(-COS(PHI1)*UJ(I,ISEG,IEDGE) + COS(PHI2)*UI(I,ISEG,IEDGE))
     4    /SIN(THETA(ISEG,IEDGE))
C
  350 TANGENT(I) = TANGENT(I)*DEDN
C
      GO TO 1000
C---------------------------------------------------------------------
C   EDGE OF REVOLUTION                                          MAP = 4
C---------------------------------------------------------------------
C---PROJECTION ALONG AXIS AND RADIUS
C
  400 RP = (RPA2(ISEG,IEDGE)-RPA1(ISEG,IEDGE))*RATIO + RPA1(ISEG,IEDGE)
      RM = ( RM2(ISEG,IEDGE)- RM1(ISEG,IEDGE))*RATIO +  RM1(ISEG,IEDGE)
C
C---ANGLE
C
      GAMMA = THETA(ISEG,IEDGE)*RATIO
C
C---CALCULATE THE POSITION AND TANGENT-----------------------------------
C
      DO 410 I=1,3
C
              UR =  COS(GAMMA)*UI(I,ISEG,IEDGE)
     &              + SIN(GAMMA)*UJ(I,ISEG,IEDGE)
```

```
C
        POINT(I) =  COEFE(I,ISEG,IEDGE) + RP*UK(I,ISEG,IEDGE) + RM*UR
C
  410 TANGENT(I) =  COS(GAMMA)*UJ(I,ISEG,IEDGE)
     &             - SIN(GAMMA)*UI(I,ISEG,IEDGE)
C
      GO TO 1000
C----------------------------------------------------------------------
C     HGM HOLE (EDGES 1,6,9,5)                                 MAP = 5
C----------------------------------------------------------------------
C---ANGULAR LOCATION (B)
C
  500       BETAI = COEFE(1,1,IEDGE)
            BETAF = COEFE(2,1,IEDGE)
C
             DBTA = BETAF - BETAI
                B = BETAI + RATIO*DBTA
C
C---CALCULATE HOLE RADIUS (RHO)
C
      CALL DELRAD(B,RHO,DRHO,RHOD,RDOC)
C
C---CALCULATE AXIAL DISTANCE (CP)
C
      CALL CAXIS(B,RHO,CP)
C
C---CALCULATE COORDINATES OF POINT ON HOLE
C
      CALL HOLE(B,POINT,VDUM)
C
C---TANGENT------------------------------------------------------------
C
               CB = COS(B)
               SB = SIN(B)
C
C---RADIAL UNIT VECTOR
C
            XR(1) = CB*DU2(1) + SB*DU3(1)
            XR(2) = CB*DU2(2) + SB*DU3(2)
            XR(3) = CB*DU2(3) + SB*DU3(3)
C
      CALL DERIV(B,RHO,CP,DRDB,DCDB)
C
      CALL VADD(DCDB,DU1,DRDB,XR,TANGENT,VDUM)
C
C---TANGENT
C
      TANGENT(1) = (RHO*(-SB*DU2(1) + CB*DU3(1)) + TANGENT(1))*DBTA
      TANGENT(2) = (RHO*(-SB*DU2(2) + CB*DU3(2)) + TANGENT(2))*DBTA
      TANGENT(3) = (RHO*(-SB*DU2(3) + CB*DU3(3)) + TANGENT(3))*DBTA
C
      GO TO 1000
C----------------------------------------------------------------------
C     DUCT EXIT PLANE (EDGES 3,7,8,11)                         MAP = 6
C----------------------------------------------------------------------
C---ANGULAR LOCATION (B)
C
  600       BETAI = COEFE(1,1,IEDGE)
            BETAF = COEFE(2,1,IEDGE)
C
```

```
               DBTA = BETAF - BETAI
                  B = BETAI + RATIO*DBTA
C
C---CALCULATE COORDINATES OF POINTS ON THE EXIT PLANE
C
      CALL DEXIT(B,POINT,VDUM)
C
C---TANGENT-------------------------------------------------------------
C
                 CB = COS(B)
                 SB = SIN(B)
C
C---DUCT RADIUS (RHOD)
C
                EX1 = (AD*SB)**2 + (BD*CB)**2
                EX2 = BD**2 - AD**2
C
               RHOD = AD*BD/SQRT(EX1)
C
              DRDDB = RHOD*SB*CB*EX2/EX1
               DCDB = (RHOD*CB + SB*DRDDB)*DFNB/(CQ - CE)
C
      CALL VADD(CB,DU2,SB,DU3,XR,VDUM)
C
      CALL VADD(DCDB,DU1,DRDDB,XR,XP,VDUM)
C
      CALL VADD(-SB,DU2,CB,DU3,XN,VDUM)
C
C---TANGENT
C
      TANGENT(1) = (XP(1) + RHOD*XN(1))*DBTA
      TANGENT(2) = (XP(2) + RHOD*XN(2))*DBTA
      TANGENT(3) = (XP(3) + RHOD*XN(3))*DBTA
C
      GO TO 1000
C----------------------------------------------------------------------
C     WELD (EDGES 2,4,10,12)                                    MAP = 7
C----------------------------------------------------------------------
C---ANGULAR LOCATION (BB)
C
  700                   PI2 = 1.57079633
C
                         BB = COEFE(1,1,IEDGE)
      IF(RATIO.LT.0.0) BB = POINT(1)
C
                      RATIO = ABS(RATIO)
C
C---WELD RADIUS (RDOC) & DIFFERENCE BETWEEN HOLE AND DUCT RADIUS (DRHO)
C
      CALL DELRAD(BB,RHO,DRHO,RHOD,RDOC)
C
C---CALCULATE AXIAL DISTANCE (CP)
C
      CALL CAXIS(BB,RHO,CP)
C
         Y = RDOC - DRHO
C
       AAD = 0.5*((ABOT + ATOP) + (ATOP - ABOT)*COS(BB - PI2))
         X = SQRT(DRHO*(2.0*RDOC - DRHO))
C
```

```
C---WELD ANGLE
C
       TH2 = ATAN(X/Y)
       TH1 = PI2 - TH2
C
        XX = AAD - X
C
       TH3 = ATAN(XX/RDOC)
C
      ANGL = RATIO*(TH2 + TH3) + TH1
C
C---POINT & TANGENT----------------------------------------------------
C
      IF(ANGL.GE.PI2) THEN
C
C---DUCT---------------------------------------------------------------
C
                        PSI = (ANGL - PI2)/TH3
C---AXIAL DISTANCE
                         CS = CP + X + PSI*XX
C---RADIUS
                         RS = RHOD
C---COORDINATES
                     CALL DUCT(BB,RS,CS,POINT)
C---TANGENT
                     TANGENT(1) = DU1(1)
                     TANGENT(2) = DU1(2)
                     TANGENT(3) = DU1(3)
C
                     RETURN
C---WELD---------------------------------------------------------------
                     ELSE
C
                         XS = RDOC*COS(ANGL)
                         YS = RDOC*SIN(ANGL)
C---AXIAL DISTANCE
                         CS = CP + X - XS
C---RADIUS
                         RS = RHOD + RDOC - YS
C---COORDINATES
                     CALL DUCT(BB,RS,CS,POINT)
C---TANGENT
                       DXDN = TAN(ANGL)
C
                         CB = COS(BB)
                         SB = SIN(BB)
C
                     CALL VADD(CB,DU2,SB,DU3,VDUM,TANGENT)
C
                     CALL VADD(DXDN,DU1,-1.0,VDUM,C,TANGENT)
C
                     RETURN
C
                     END IF
C----------------------------------------------------------------------
C
 1000 CONTINUE
C
      RETURN
C
```

```
 1100 DO 1110 I=4,6
 1110 POINT(I) = PT1(I,ISEG,IEDGE)
C
      RETURN
      END
C
C**********************************************************************
C*****MAPPING**********************************************************
C**********************************************************************
C
      SUBROUTINE SURFACE(INIT,ISIDE)
C----------------------------------------------------------------------
C   THIS ROUTINE DETERMINES THE COORDINATES AND NORMAL OF A
C   POINT ON A SURFACE.
C----------------------------------------------------------------------
      COMMON /COEFF/   COEFE(8,10,12),COEFS(8,6),NMBRSEG(12)
      COMMON /COORD/   UA(3,6),UE(3,6),UN(3,6)
      COMMON /COUNTER/ NODESAV,NODETOT,NBNODES,NPLANE
      COMMON /HEADER/  ITITLE(20),LINE
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /INITB/   IBOX(4,6),IRAY(4,3),NRAY,IPT1(12),IPT2(12)
      COMMON /INITC/   PI,RADDEG
      COMMON /INPUTA/  EDGE(3,12),POINT(3,8),SIDE(3,6)
      COMMON /MARCHS/  MARCH,INDEX(3)
      COMMON /MAPED/   KSEG(12),UAXIS(3,6),IEDGE1(6),IEDGE2(6),GAMMA
      COMMON /MAPING/  MAPSIDE(6),MAPSEG(10,12)
      COMMON /MAXIMUM/ ETAMAX(10,12),SEGMAX(3,10,12)
      COMMON /PARTIAL/ DEDN(3,12),DSDN(3,2),SNORMAL(3,6)
      COMMON /SPACING/ ISTRTCH(3),STRETCH(3),ETAS(3,200),ETA(3),DETA(3)
      COMMON /UNITS/   NU5,NU6,NU20
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
C
      COMMON /DFN1/    DU1(3),DU2(3),DU3(3),DFNB,DFND,DFNF
      COMMON /DFN2/    AE,BE,DFNR,ZSTAR,AGL,BETA1,BETA2,BETA3,BETA4
      COMMON /DFN3/    AD,BD,BETA(37),DELRHO(37),RADOC(37)
      COMMON /DFN4/    IHOLE,PL(6,6,4),PA(2,6,4)
      COMMON /DFN5/    CE,CQ,ABOT,ATOP
C
      DIMENSION RAM(3),SAC(3)
      DIMENSION R1(6),R2(6),R3(6),R4(6)
      DIMENSION E1(6),E2(6),E3(6),E4(6)
C
      DIMENSION F(8)
      DIMENSION NMBRPT(4,6),SPOINT(3,4,6),SEDGE(3,4),SWEEP(3)
      DIMENSION UNORMAL(3,6),URADIAL(3,6)
      DIMENSION ZERO(3),VECTOR(3)
      DIMENSION IETA1(6),IETA2(6),SIGNS(6)
      DIMENSION UNITRAD(3)
C
      DATA IETA1 /1,1,1,1,2,2/
      DATA IETA2 /2,3,2,3,3,3/
      DATA SIGNS /1.0,-1.0,-1.0,1.0,1.0,-1.0/
      DATA ZERO  /0.,0.,0./
C
      NODNUM = NODESAV + NODETOT + 1
C
C---ETA COEFFICIENTS FOR BI-LINEAR INTERPOLATION
C
        F(1) = 1.0 - ETA(IETA1(ISIDE))
        F(2) =       ETA(IETA1(ISIDE))
```

```
         F(3) = 1.0 - ETA(IETA2(ISIDE))
         F(4) =       ETA(IETA2(ISIDE))
         F(5) = F(1)*F(3)
         F(6) = F(1)*F(4)
         F(7) = F(2)*F(3)
         F(8) = F(2)*F(4)
C
C---DETERMINE THE EDGES OF THE SURFACE
C
        LINE1 = IBOX(1,ISIDE)
        LINE2 = IBOX(2,ISIDE)
        LINE3 = IBOX(3,ISIDE)
        LINE4 = IBOX(4,ISIDE)
C
C---DETERMINE THE CORNER POINTS OF THE SURFACE
C
         LPT1 = IPT1(LINE1)
         LPT2 = IPT1(LINE3)
         LPT3 = IPT2(LINE3)
         LPT4 = IPT2(LINE1)
C
                                              MAP = MAPSIDE(ISIDE)
C
      GO TO (100,100,300,400,500,600,700) MAP
C-----------------------------------------------------------------------
C   FLAT OR CYLINDRICAL SURFACE                               MAP = 1 OR 2
C-----------------------------------------------------------------------
C---CALCULATE POSITION
C
  100 DO 110 J=1,3
C
          SIDE(J,ISIDE) =  F(1)*EDGE(J,LINE1) - F(5)*POINT(J,LPT1)
     1                   + F(2)*EDGE(J,LINE3) - F(6)*POINT(J,LPT4)
     2                   + F(3)*EDGE(J,LINE2) - F(7)*POINT(J,LPT2)
     3                   + F(4)*EDGE(J,LINE4) - F(8)*POINT(J,LPT3)
C
              DSDN(J,1) =       EDGE(J,LINE3) + F(3)*POINT(J,LPT1)
     1                        - EDGE(J,LINE1) + F(4)*POINT(J,LPT4)
     2                   + F(3)*DEDN(J,LINE2) - F(3)*POINT(J,LPT2)
     3                   + F(4)*DEDN(J,LINE4) - F(4)*POINT(J,LPT3)
C
  110         DSDN(J,2) =       EDGE(J,LINE4) + F(1)*POINT(J,LPT1)
     1                        - EDGE(J,LINE2) + F(2)*POINT(J,LPT2)
     2                   + F(1)*DEDN(J,LINE1) - F(1)*POINT(J,LPT4)
     3                   + F(2)*DEDN(J,LINE3) - F(2)*POINT(J,LPT3)
C
      CALL CROSS(DSDN(1,1),DSDN(1,2),SNORMAL(1,ISIDE),41)
C
      GO TO 1000
C-----------------------------------------------------------------------
C   SPECIAL SURFACE                                              MAP = 3
C-----------------------------------------------------------------------
  300 GO TO 1000
C-----------------------------------------------------------------------
C   EDGE OF REVOLUTION                                           MAP = 4
C-----------------------------------------------------------------------
  400 IF(INIT.EQ.1) THEN
C
C---ETA DIRECTION OF REVOLUTION
C
```

```
                                           IONETWO = 1
      IF(COEFS(7,ISIDE).EQ.IETA2(ISIDE)) IONETWO = 2
C
C---EDGE 1
C
              IEDGE1(ISIDE) = IBOX(IONETWO,ISIDE)
C
C---EDGE 2
C
              IEDGE2(ISIDE) = IBOX(IONETWO + 2,ISIDE)
C
C---UA: NORMALIZED VECTOR ALONG AXIS OF REVOLUTION
C
      CALL VADD(1.0,COEFS(4,ISIDE),1.0,ZERO,VECTOR,UA(1,ISIDE))
C
C---UN: NORMALIZED VECTOR FROM AXIS TOWARD SURFACE
C
      CALL VADD(1.0,EDGE(1,IEDGE1(ISIDE)),-1.0,COEFS(1,ISIDE),E1,VECTOR)
C
      CALL CROSS(UA(1,ISIDE),E1,UN(1,ISIDE),42)
C
C---UE: NORMALIZED VECTOR FROM AXIS TO FIRST EDGE
C
      CALL CROSS(UN(1,ISIDE),UA(1,ISIDE),UE(1,ISIDE),43)
C
                    END IF
C
C---R1: VECTOR FROM AXIS TO FIRST EDGE----------------------------------
C
      CALL VADD(1.0,EDGE(1,IEDGE1(ISIDE)),-1.0,COEFS(1,ISIDE),E1,VECTOR)
C
      CALL VDOT(E1,UA(1,ISIDE),EPA1)
C
      CALL VADD(1.0,E1,-EPA1,UA(1,ISIDE),R1,VECTOR)
C
      CALL VMAG(R1,RM1)
C
C---DERIVATIVE
C
      CALL VDOT(DEDN(1,IEDGE1(ISIDE)),UA(1,ISIDE),DA1)
C
      CALL VDOT(DEDN(1,IEDGE1(ISIDE)),VECTOR,DR1)
C
      CALL VMAG(DEDN(1,IEDGE1(ISIDE)),DM1)
C
C---R2: VECTOR FROM AXIS TO SECOND EDGE---------------------------------
C
      CALL VADD(1.0,EDGE(1,IEDGE2(ISIDE)),-1.0,COEFS(1,ISIDE),E2,VECTOR)
C
      CALL VDOT(E2,UA(1,ISIDE),EPA2)
C
      CALL VADD(1.0,E2,-EPA2,UA(1,ISIDE),R2,VECTOR)
C
      CALL VMAG(R2,RM2)
C
C---DERIVATIVE
C
      CALL VDOT(DEDN(1,IEDGE2(ISIDE)),UA(1,ISIDE),DA2)
C
      CALL VDOT(DEDN(1,IEDGE2(ISIDE)),VECTOR,DR2)
```

```
C
      CALL VMAG(DEDN(1,IEDGE2(ISIDE)),DM2)
C
C---SWEEP ANGLE-----------------------------------------------------------
C
      CALL VDOT(R1,R2,R1DOTR2)
C
                                ARG = R1DOTR2/(RM1*RM2)
C
      IF(ABS(ARG).GT.1.0) ARG = ARG/ABS(ARG)
C
      THETA = ACOS(ARG)
C
C---CALCULATE RADIUS------------------------------------------------------
C
          N = COEFS(7,ISIDE)
C
C---POSITION
C
         EP = (EPA2 - EPA1)*ETA(N) + EPA1
         RM = (RM2  - RM1 )*ETA(N) + RM1
C
C---DERIVATIVE
C
         DA = (DA2 - DA1)*ETA(N) + DA1
         DR = (DR2 - DR1)*ETA(N) + DR1
         DM = (DM2 - DM1)*ETA(N) + DM1
C
C---ANGLE
C
      GAMMA = THETA*ETA(N)
C
C---CALCULATE THE POSITION AND SURFACE NORMAL-----------------------------
C
      DO 410 I=1,3
C
                UR =  COS(GAMMA)*UE(I,ISIDE) + SIN(GAMMA)*UN(I,ISIDE)
C
      SIDE(I,ISIDE) =  COEFS(I,ISIDE) + EP*UA(I,ISIDE) + RM*UR
C
          DSDN(I,1) =  (DR*UR + DA*UA(I,ISIDE))/DM
C
  410     DSDN(I,2) =  COS(GAMMA)*UN(I,ISIDE) - SIN(GAMMA)*UE(I,ISIDE)
C
C---ORIENT SURFACE NORMAL DEPENDING ON DIRECTION OF EDGE REVOLUTION
C
      IF(COEFS(7,ISIDE).EQ.IETA2(ISIDE)) THEN
C
      CALL CROSS(DSDN(1,1),DSDN(1,2),SNORMAL(1,ISIDE),44)
C
                                    ELSE
C
      CALL CROSS(DSDN(1,2),DSDN(1,1),SNORMAL(1,ISIDE),45)
C
                                    END IF
      GO TO 1000
C------------------------------------------------------------------------
C     BOWL SURFACE WITH HOLE                                     MAP = 5
C------------------------------------------------------------------------
  500 IHOLE = 0
```

```
C
                             IET1 = 1
      IF(ETA(1).GE.ETAMAX(1,3)) IET1 = 2
      IF(ETA(1).GE.ETAMAX(2,3)) IET1 = 3
      IF(ETA(1).GE.ETAMAX(3,3)) IET1 = 4
      IF(ETA(1).GE.ETAMAX(4,3)) IET1 = 5
C
            STR11 = 2.0
            STR12 = 6.0
            STR13 = 2.0
C
             EPS1 = ETA(1)/ETAMAX(1,3)
C
      IF(IET1.EQ.2 .OR. IET1.EQ.3) THEN
C
           RATIO1 = (ETA(1) - ETAMAX(1,3)) / (ETAMAX(3,3) - ETAMAX(1,3))
C
               X1 = RATIO1*STR11/2.0
            ETAX1 = (EXP(X1) - EXP(-X1))/(EXP(X1) + EXP(-X1))
C
               X2 = STR11/2.0
            ETAX2 = (EXP(X2) - EXP(-X2))/(EXP(X2) + EXP(-X2))
C
             EPX1 = ETAX1/ETAX2
C
                                 END IF
C
      IF(IET1.EQ.4) THEN
C
           RATIO1 = (ETA(1) - ETAMAX(3,3)) / (ETAMAX(4,3) - ETAMAX(3,3))
C
               X1 = (STR12/2.0)/2.0
           ETAMID = (EXP(X1) - EXP(-X1))/(EXP(X1) + EXP(-X1))
C
               X2 = (RATIO1 - 0.5)*STR12/2.0
            ETAMX = (EXP(X2) - EXP(-X2))/(EXP(X2) + EXP(-X2))
C
             EPS1 = (ETAMX + ETAMID)/(2.0*ETAMID)
C
                     END IF
C
      IF(IET1.EQ.5) THEN
C
           RATIO1 = (ETA(1) - ETAMAX(4,3)) / (1.0 - ETAMAX(4,3))
C
               X1 = (STR13/2.0)/2.0
           ETAMID = (EXP(X1) - EXP(-X1))/(EXP(X1) + EXP(-X1))
C
               X2 = (RATIO1 - 0.5)*STR13/2.0
            ETAMX = (EXP(X2) - EXP(-X2))/(EXP(X2) + EXP(-X2))
C
             EPS1 = (ETAMX + ETAMID)/(2.0*ETAMID)
C
                     END IF
C
                             IET3 = 1
      IF(ETA(3).GE.ETAMAX(1,8)) IET3 = 2
      IF(ETA(3).GT.ETAMAX(2,8)) IET3 = 3
C
            STR31 = 2.0
```

```
          STR32 = 4.0
          STR33 = 2.0
C
      IF(IET3.EQ.1) THEN
C
          RATIO3 = ETA(3)/ETAMAX(1,8)
C
              X1 = RATIO3*STR31/2.0
           ETAX1 = (EXP(X1) - EXP(-X1))/(EXP(X1) + EXP(-X1))
C
              X2 = STR31/2.0
           ETAX2 = (EXP(X2) - EXP(-X2))/(EXP(X2) + EXP(-X2))
C
            EPS3 = ETAX1/ETAX2
C
                    END IF
C
      IF(IET3.EQ.2) THEN
C
          RATIO3 = (ETA(3) - ETAMAX(1,8))/(ETAMAX(2,8) - ETAMAX(1,8))
C
              X1 = (STR32/2.0)/2.0
          ETAMID = (EXP(X1) - EXP(-X1))/(EXP(X1) + EXP(-X1))
C
              X2 = (RATIO3 - 0.5)*STR32/2.0
           ETAMX = (EXP(X2) - EXP(-X2))/(EXP(X2) + EXP(-X2))
C
            EPS3 = (ETAMX + ETAMID)/(2.0*ETAMID)
C
                    END IF
C
      IF(IET3.EQ.3) THEN
C
          RATIO3 = 1.0 - (ETA(3) - ETAMAX(2,8))/(1.0 - ETAMAX(2,8))
C
              X1 = RATIO3*STR33/2.0
           ETAX1 = (EXP(X1) - EXP(-X1))/(EXP(X1) + EXP(-X1))
C
              X2 = STR33/2.0
           ETAX2 = (EXP(X2) - EXP(-X2))/(EXP(X2) + EXP(-X2))
C
            EPS3 = 1.0 - ETAX1/ETAX2
C
                    END IF
C
C---BOWL AXIS
C
      UAXIS(1,ISIDE) = 1.0
      UAXIS(2,ISIDE) = 0.0
      UAXIS(3,ISIDE) = 0.0
C
C---ARC CENTER ON AXIS
C
         SAC(2) = 0.0
         SAC(3) = 0.0
C
      DO 510 J=1,6
C
C---SUB-SURFACE CORNER POINTS
C
```

```
         R1(J) = PL(J,IET1  ,IET3)
         R2(J) = PL(J,IET1+1,IET3)
         R3(J) = PL(J,IET1+1,IET3+1)
         R4(J) = PL(J,IET1  ,IET3+1)
C
C---SUB-SURFACE EDGE POINTS
C
         E1(J) = R1(J) + EPS1*(R2(J) - R1(J))
         E2(J) = R2(J) + EPS3*(R3(J) - R2(J))
         E3(J) = R4(J) + EPS1*(R3(J) - R4(J))
  510    E4(J) = R1(J) + EPS3*(R4(J) - R1(J))
C
      GO TO (520,540,560) IET3
C-----------------------------------------------------------------------
C                                                               IET3 = 1
C-----------------------------------------------------------------------
  520 GO TO (522,524,524,528,530) IET1
C
C---IET1 = 1------------------------------------------------------------
C
  522 DO 523 J=1,6
            E1(J) = EDGE(J,3)
  523       E4(J) = EDGE(J,8)
C
           SAC(1) = SEGMAX(1,1,3)
C
      CALL SPEDGE(R2,R3,EPS3,SAC,E2)
C
      GO TO 580
C
C---IET1 = 2------------------------------------------------------------
C
 524        R2(1) = PL(1,4,IET3)
            R3(1) = PL(1,4,IET3+1)
C
            E2(1) = R2(1) + EPS3*(R3(1) - R2(1))
C
              EXM = SEGMAX(1,1,3) + EPX1*(E2(1) - SEGMAX(1,1,3))
C
         IF(EXM.GT.SEGMAX(1,2,3)) GO TO 526
C
C---INTERIOR
C
             EPS1 = (EXM -SEGMAX(1,1,3))/(SEGMAX(1,2,3) -SEGMAX(1,1,3))
C
C---SUB-SURFACE EDGE POINTS
C
             IET1 = 2
C
            DO 525 J=1,6
C
            R1(J) = PL(J,IET1  ,IET3)
            R2(J) = PL(J,IET1+1,IET3)
            R3(J) = PL(J,IET1+1,IET3+1)
            R4(J) = PL(J,IET1  ,IET3+1)
C
            E1(J) = EDGE(J,3)
  525       E3(J) = R4(J) + EPS1*(R3(J) - R4(J))
C
           SAC(1) = SEGMAX(1,2,3)
```

```
C
      CALL SPEDGE(R2,R3,EPS3,SAC,E2)
C
            SAC(1) = SEGMAX(1,1,3)
C
      CALL SPEDGE(R1,R4,EPS3,SAC,E4)
C
      GO TO 580
C
C---IET1 = 3---------------------------------------------------------
C
  526        EPS1 = (EXM - SEGMAX(1,2,3))/(E2(1) - SEGMAX(1,2,3))
C
C---SUB-SURFACE EDGE POINTS
C
             IET1 = 3
C
            DO 527 J=1,6
C
            R1(J) = PL(J,IET1  ,IET3)
            R2(J) = PL(J,IET1+1,IET3)
            R3(J) = PL(J,IET1+1,IET3+1)
            R4(J) = PL(J,IET1  ,IET3+1)
C
            E1(J) = EDGE(J,3)
  527       E3(J) = R4(J) + EPS1*(R3(J) - R4(J))
C
            SAC(1) = SEGMAX(1,3,3)
C
      CALL SPEDGE(R2,R3,EPS3,SAC,E2)
C
            SAC(1) = SEGMAX(1,2,3)
C
      CALL SPEDGE(R1,R4,EPS3,SAC,E4)
C
      GO TO 580
C
C---IET1 = 4---------------------------------------------------------
C
  528 DO 529 J=1,6
C
  529       E1(J) = EDGE(J,3)
C
            SAC(1) = SEGMAX(1,4,3)
C
      CALL SPEDGE(R2,R3,EPS3,SAC,E2)
C
            SAC(1) = SEGMAX(1,3,3)
C
      CALL SPEDGE(R1,R4,EPS3,SAC,E4)
C
                  B = BETA1 + EPS1*(BETA2 - BETA1)
C
      CALL HOLE(B,E3,VECTOR)
C
      GO TO 580
C
C---IET1 = 5---------------------------------------------------------
C
  530 DO 531 J=1,6
```

```
C
           E1(J) = EDGE(J,3)
  531      E2(J) = EDGE(J,7)
C
          SAC(1) = SEGMAX(1,4,3)
C
      CALL SPEDGE(R1,R4,EPS3,SAC,E4)
C
      GO TO 580
C-----------------------------------------------------------------------
C                                                                IET3 = 2
C-----------------------------------------------------------------------
  540 GO TO (542,544,544,548,550) IET1
C
C---IET1 = 1------------------------------------------------------------
C
  542 DO 543 J=1,6
C
  543      E4(J) = EDGE(J,8)
C
          SAC(1) = SEGMAX(1,1,3)
C
      CALL SPEDGE(R2,R3,EPS3,SAC,E2)
C
      GO TO 580
C
C---IET1 = 2------------------------------------------------------------
C
  544            B = BETA1 + EPS3*(BETA4 - BETA1)
C
      CALL HOLE(B,E2,VECTOR)
C
             EXM = SEGMAX(1,1,3) + EPX1*(E2(1) - SEGMAX(1,1,3))
C
      IF(EXM.GT.SEGMAX(1,2,3)) GO TO 546
C
C---INTERIOR
C
            EPS1 = (EXM -SEGMAX(1,1,3))/(SEGMAX(1,2,3) -SEGMAX(1,1,3))
C
C---SUB-SURFACE EDGE POINTS
C
            IET1 = 2
C
          DO 545 J=1,6
C
          R1(J) = PL(J,IET1  ,IET3)
          R2(J) = PL(J,IET1+1,IET3)
          R3(J) = PL(J,IET1+1,IET3+1)
          R4(J) = PL(J,IET1  ,IET3+1)
C
          E1(J) = R1(J) + EPS1*(R2(J) - R1(J))
  545     E3(J) = R4(J) + EPS1*(R3(J) - R4(J))
C
         SAC(1) = SEGMAX(1,2,3)
C
      CALL SPEDGE(R2,R3,EPS3,SAC,E2)
C
         SAC(1) = SEGMAX(1,1,3)
C
```

```
      CALL SPEDGE(R1,R4,EPS3,SAC,E4)
C
      GO TO 580
C
C---IET1 = 3-----------------------------------------------------------
C
  546         EPS1 = (EXM - SEGMAX(1,2,3))/(E2(1) - SEGMAX(1,2,3))
C
C---SUB-SURFACE EDGE POINTS
C
              IET1 = 3
C
             DO 547 J=1,6
C
             R1(J) = PL(J,IET1  ,IET3)
             R2(J) = PL(J,IET1+1,IET3)
             R3(J) = PL(J,IET1+1,IET3+1)
             R4(J) = PL(J,IET1  ,IET3+1)
C
             E1(J) = R1(J) + EPS1*(R2(J) - R1(J))
  547        E3(J) = R4(J) + EPS1*(R3(J) - R4(J))
C
            SAC(1) = SEGMAX(1,2,3)
C
      CALL SPEDGE(R1,R4,EPS3,SAC,E4)
C
                  B = BETA1 + EPS3*(BETA4 - BETA1)
C
      CALL HOLE(B,E2,VECTOR)
C
      GO TO 580
C
C---IET1 = 4-----------------------------------------------------------
C
  548        IHOLE = 1
C
                  B = BETA1 + EPS1*(BETA2 - BETA1)
C
      CALL HOLE(B,E1,VECTOR)
C
                  B = BETA2 + EPS3*(BETA3 - BETA2 - 2.*PI)
C
      CALL HOLE(B,E2,VECTOR)
C
                  B = BETA4 + EPS1*(BETA3 - BETA4)
C
      CALL HOLE(B,E3,VECTOR)
C
                  B = BETA1 + EPS3*(BETA4 - BETA1)
C
      CALL HOLE(B,E4,VECTOR)
C
      GO TO 580
C
C---IET1 = 5-----------------------------------------------------------
C
  550 DO 551 J=1,6
C
  551        E2(J) = EDGE(J,7)
C
```


C-2

```
                  B = BETA2 + EPS3*(BETA3 - BETA2 - 2.*PI)
C
      CALL HOLE(B,E4,VECTOR)
C
      GO TO 580
C-----------------------------------------------------------------------
C                                                              IET3 = 3
C-----------------------------------------------------------------------
  560 GO TO (562,564,564,568,570) IET1
C
C---IET1 = 1-----------------------------------------------------------
C
  562 DO 563 J=1,6
C
            E3(J) = EDGE(J,11)
  563       E4(J) = EDGE(J,8)
C
           SAC(1) = SEGMAX(1,1,3)
C
      CALL SPEDGE(R2,R3,EPS3,SAC,E2)
C
      GO TO 580
C
C---IET1 = 2-----------------------------------------------------------
C
  564       R2(1) = PL(1,4,IET3)
            R3(1) = PL(1,4,IET3+1)
C
            E2(1) = R2(1) + EPS3*(R3(1) - R2(1))
C
              EXM = SEGMAX(1,1,3) + EPX1*(E2(1) - SEGMAX(1,1,3))
C
      IF(EXM.GT.SEGMAX(1,2,3)) GO TO 566
C
C---INTERIOR
C
             EPS1 = (EXM -SEGMAX(1,1,3))/(SEGMAX(1,2,3) -SEGMAX(1,1,3))
C
             IET1 = 2
C
            DO 565 J=1,6
C
            R1(J) = PL(J,IET1  ,IET3)
            R2(J) = PL(J,IET1+1,IET3)
            R3(J) = PL(J,IET1+1,IET3+1)
            R4(J) = PL(J,IET1  ,IET3+1)
C
            E1(J) = R1(J) + EPS1*(R2(J) - R1(J))
  565       E3(J) = EDGE(J,11)
C
           SAC(1) = SEGMAX(1,2,3)
C
      CALL SPEDGE(R2,R3,EPS3,SAC,E2)
C
           SAC(1) = SEGMAX(1,1,3)
C
      CALL SPEDGE(R1,R4,EPS3,SAC,E4)
C
      GO TO 580
C
```

```
C---IET1 = 3---------------------------------------------------------
C
 566        EPS1 = (EXM - SEGMAX(1,2,3))/(E2(1) - SEGMAX(1,2,3))
C
            IET1 = 3
C
           DO 567 J=1,6
C
           R1(J) = PL(J,IET1  ,IET3)
           R2(J) = PL(J,IET1+1,IET3)
           R3(J) = PL(J,IET1+1,IET3+1)
           R4(J) = PL(J,IET1  ,IET3+1)
C
           E1(J) = R1(J) + EPS1*(R2(J) - R1(J))
           E2(J) = R2(J) + EPS3*(R3(J) - R2(J))
 567       E3(J) = EDGE(J,11)
C
          SAC(1) = SEGMAX(1,2,3)
C
      CALL SPEDGE(R1,R4,EPS3,SAC,E4)
C
      GO TO 580
C
C---IET1 = 4---------------------------------------------------------
C
 568 DO 569 J=1,6
C
 569       E3(J) = R4(J) + EPS1*(R3(J) - R4(J))
C
               B = BETA4 + EPS1*(BETA3 - BETA4)
C
      CALL HOLE(B,E1,VECTOR)
C
      GO TO 580
C
C---IET1 = 5---------------------------------------------------------
C
 570 DO 571 J=1,6
C
           E3(J) = EDGE(J,11)
 571       E2(J) = EDGE(J,7)
C
C--------------------------------------------------------------------
C     INTERPOLATION
C--------------------------------------------------------------------
C---POSITION
C
 580 DO 582 J=1,3
C
 582 RAM(J) = (1. - EPS1)*(E4(J) - (1. - EPS3)*R1(J) - EPS3*R4(J))
    1        + EPS1*(E2(J) - (1. - EPS3)*R2(J) - EPS3*R3(J)) + E1(J)
    2        + EPS3*(E3(J) - E1(J))
C
C--------------------------------------------------------------------
C     RADIUS AND TANGENT
C--------------------------------------------------------------------
C---AXIAL DISTANCE
C
           RAX = RAM(1)
C
```

```
C---REGION 1-------------------------------------------------------------
C
      IF(RAX.GT.SEGMAX(1,1,3)) GO TO 586
C
C---RADIUS
C
              PSI = RAX/SEGMAX(1,1,3)
C
             RAD1 = SQRT(    POINT(2,4)**2 +     POINT(3,4)**2)
             RAD2 = SQRT(SEGMAX(2,1,3)**2 + SEGMAX(3,1,3)**2)
C
              RAD = RAD1 + PSI*(RAD2 - RAD1)
C
C---TANGENT
C
      DSDN(1,1) = SEGMAX(1,1,3) - POINT(1,4)
      DSDN(2,1) = RAD2 - RAD1
      DSDN(3,1) = 0.
C
      GO TO 590
C
C---REGION 2-------------------------------------------------------------
C
  586 IF(RAX.GT.SEGMAX(1,2,3)) GO TO 588
C
C---RADIUS
C
              PSI = (RAX - SEGMAX(1,1,3))/(SEGMAX(1,2,3) - SEGMAX(1,1,3))
C
             RAD1 = SQRT(SEGMAX(2,1,3)**2 + SEGMAX(3,1,3)**2)
             RAD2 = SQRT(SEGMAX(2,2,3)**2 + SEGMAX(3,2,3)**2)
C
              RAD = RAD1 + PSI*(RAD2 - RAD1)
C
C---TANGENT
C
      DSDN(1,1) = SEGMAX(1,2,3) - SEGMAX(1,1,3)
      DSDN(2,1) = RAD2 - RAD1
      DSDN(3,1) = 0.
C
      GO TO 590
C
C---REGION 3-------------------------------------------------------------
C
C---ELLIPTIC REGION OF BOWL
C
C---RADIUS
C
  588         RAD = DFNR + BE*SQRT(1.0 - ((RAX - DFND)/AE)**2)
C
C---TANGENT
C
             DRDX = -((BE/AE)**2)*(RAX - DFND)/(RAD - DFNR)
C
               TH = ATAN(DRDX)
C
      DSDN(1,1) = COS(TH)
      DSDN(2,1) = SIN(TH)
      DSDN(3,1) = 0.0
C
```

```
C---INSIDE HOLE
C
      IF(IET3.EQ.2 .AND. IET1.EQ.4) THEN
C
             I = 0
         THETA = ATAN( RAM(2) / RAM(3) )
C
      DO 587 J=1,36
C
      CALL HOLE(BETA(J),E1,VECTOR)
C
        THETA1 = ATAN( E1(2) / E1(3) )
C
      CALL HOLE(BETA(J+1),E2,VECTOR)
C
        THETA2 = ATAN( E2(2) / E2(3) )
C
                                                  MATCH = 0
      IF(THETA.GT.THETA1 .AND. THETA.LT.THETA2) MATCH = 1
      IF(THETA.GT.THETA2 .AND. THETA.LT.THETA1) MATCH = 2
C
      IF(MATCH.GT.0) THEN
C
             I = I + 1
C
      IF(MATCH.EQ.1) THEN
C
                    RATIO = (THETA - THETA1) / (THETA2 - THETA1)
C
                        B = RATIO*(BETA(J+1) - BETA(J)) + BETA(J)
C
                    ELSE
C
                    RATIO = (THETA - THETA2) / (THETA1 - THETA2)
C
                        B = RATIO*(BETA(J) - BETA(J+1)) + BETA(J+1)
C
                    END IF
C
      IF(I.EQ.1) THEN
C
                CALL HOLE(B,E3,VECTOR)
C
                  RAD1 = SQRT( E3(2)**2 + E3(3)**2)
C
                  GO TO 587
C
                ELSE
C
                CALL HOLE(B,E4,VECTOR)
C
                  RAD2 = SQRT( E4(2)**2 + E4(3)**2)
C
                  GO TO 589
C
                END IF
C
                    END IF
  587 CONTINUE
  589 CONTINUE
```

```
C
      IF(E3(1).LT.E4(1)) THEN
C
                              RATIO = (RAM(1) - E3(1)) / (E4(1) - E3(1))
C
                                RAD = RATIO*(RAD2 - RAD1) + RAD1
C
                              ELSE
C
                              RATIO = (RAM(1) - E4(1)) / (E3(1) - E4(1))
C
                                RAD = RATIO*(RAD1 - RAD2) + RAD2
C
                              END IF
C
                                      DSDN(1,1) = 1.0
                                      DSDN(2,1) = 0.0
                                      DSDN(3,1) = 0.0
C
                                         END IF
C---BELOW HOLE
C
      IF(IET3.EQ.3 .AND. RAX.LE.SEGMAX(1,4,11)) THEN
C
                                             RAD = SQRT(RAM(2)**2 + RAM(3)**2)
C
                                      DSDN(1,1) = 1.0
                                      DSDN(2,1) = 0.0
                                      DSDN(3,1) = 0.0
C
                                                         END IF
C-----------------------------------------------------------------------
C     OUTPUT POSITION AND NORMAL
C-----------------------------------------------------------------------
C---AXIAL COMPONENT OF THE TANGENT
C
  590 CALL VDOT(DSDN(1,1),UAXIS(1,ISIDE),DA)
C
C---NORMAL COMPONENT OF THE TANGENT
C
             DN = DSDN(2,1)
C
C---INTERPOLATED RADIUS
C
           RADX = SQRT(RAM(2)**2 + RAM(3)**2)
C
C---ANGULAR LOCATION
C
            ANG = ASIN(RAM(3)/RADX)
C
           CANG = COS(ANG)
           SANG = SIN(ANG)
C
C---TANGENT 1 (AXIAL DIRECTION)
C
      DSDN(1,1) = DA
      DSDN(2,1) = DN*CANG
      DSDN(3,1) = DN*SANG
C
C---TANGENT 2 (CIRCUMFERENTIAL DIRECTION)
```

```
C
      DSDN(1,2) =  0.0
      DSDN(2,2) = -SANG
      DSDN(3,2) =  CANG
C
C---NORMAL
C
      CALL CROSS(DSDN(1,1),DSDN(1,2),SNORMAL(1,ISIDE),45)
C
C---POSITION
C
                      SIDE(1,ISIDE) = RAX
                      SIDE(2,ISIDE) = RAD*CANG
                      SIDE(3,ISIDE) = RAD*SANG
C
      IF(EPS3.EQ.1.0) THEN
C
                      SIDE(1,ISIDE) = E3(1)
                      SIDE(2,ISIDE) = E3(2)
                      SIDE(3,ISIDE) = E3(3)
C
                      END IF
C
      GO TO 1000
C-----------------------------------------------------------------------
C     MATED DUCT SURFACE                                          MAP = 6
C-----------------------------------------------------------------------
  600            IHOLE = 1
C
                  EPS1 = ETA(1)
                  EPS3 = ETA(3)
C
C---SUB-SURFACE CORNER POINTS
C
      DO 610 J=1,6
C
                 R1(J) = PL(J,4,2)
                 R2(J) = PL(J,5,2)
                 R3(J) = PL(J,5,3)
  610            R4(J) = PL(J,4,3)
C
C---SUB-SURFACE EDGES
C
                     B = BETA1 + EPS1*(BETA2 - BETA1)
C
      CALL HOLE(B,E1,VECTOR)
C
                     B = BETA2 + EPS3*(BETA3 - BETA2 - 2.*PI)
C
      CALL HOLE(B,E2,VECTOR)
C
                     B = BETA4 + EPS1*(BETA3 - BETA4)
C
      CALL HOLE(B,E3,VECTOR)
C
                     B = BETA1 + EPS3*(BETA4 - BETA1)
C
      CALL HOLE(B,E4,VECTOR)
C-----------------------------------------------------------------------
C     INTERPOLATION
```

```
C----------------------------------------------------------------------
C---POSITION
C
      DO 620 J=1,3
  620 RAM(J) = (1. - EPS1)*(E4(J) - (1. - EPS3)*R1(J) - EPS3*R4(J))
     1        + EPS1*(E2(J) - (1. - EPS3)*R2(J) - EPS3*R3(J)) + E1(J)
     2        + EPS3*(E3(J) - E1(J))
C
C----------------------------------------------------------------------
C     RADIUS AND TANGENT
C----------------------------------------------------------------------
C---AXIAL DISTANCE
C
            RAX = RAM(1)
C
C---RADIUS
C
      IF(EPS1.EQ.0. .OR.EPS1.EQ.1. .OR.EPS3.EQ.0. .OR.EPS3.EQ.1.) THEN
C
C          RAD = DFNR + BE*SQRT(1.0 - ((RAX - DFND)/AE)**2)
           RAD = SQRT(RAM(2)**2 + RAM(3)**2)
                                                                  ELSE
               I = 0
         THETA = ATAN( RAM(2) / RAM(3) )
C
      DO 640 J=1,36
C
      CALL HOLE(BETA(J),E1,VECTOR)
C
        THETA1 = ATAN( E1(2) / E1(3) )
C
      CALL HOLE(BETA(J+1),E2,VECTOR)
C
        THETA2 = ATAN( E2(2) / E2(3) )
C
                                                  MATCH = 0
      IF(THETA.GT.THETA1 .AND. THETA.LT.THETA2) MATCH = 1
      IF(THETA.GT.THETA2 .AND. THETA.LT.THETA1) MATCH = 2
C
      IF(MATCH.GT.0) THEN
C
               I = I + 1
C
      IF(MATCH.EQ.1) THEN
C
                     RATIO = (THETA - THETA1) / (THETA2 - THETA1)
C
                         B = RATIO*(BETA(J+1) - BETA(J)) + BETA(J)
C
                     ELSE
C
                     RATIO = (THETA - THETA2) / (THETA1 - THETA2)
C
                         B = RATIO*(BETA(J) - BETA(J+1)) + BETA(J+1)
C
                     END IF
C
      IF(I.EQ.1) THEN
C
                 CALL HOLE(B,E3,VECTOR)
```

```
C
                    RAD1 = SQRT( E3(2)**2 + E3(3)**2)
C
                    GO TO 640
C
                  ELSE
C
                  CALL HOLE(B,E4,VECTOR)
C
                    RAD2 = SQRT( E4(2)**2 + E4(3)**2)
C
                    GO TO 650
C
                  END IF
C
                      END IF
  640 CONTINUE
  650 CONTINUE
C
      IF(E3(1).LT.E4(1)) THEN
C
                          RATIO = (RAM(1) - E3(1)) / (E4(1) - E3(1))
C
                            RAD = RATIO*(RAD2 - RAD1) + RAD1
C
                          ELSE
C
                          RATIO = (RAM(1) - E4(1)) / (E3(1) - E4(1))
C
                            RAD = RATIO*(RAD1 - RAD2) + RAD2
C
                          END IF
                                                                    END IF
C
C---TANGENT
C
           DRDX = -((BE/AE)**2)*(RAX - DFND)/(RAD - DFNR)
             TH = ATAN(DRDX)
C
      DSDN(1,1) = COS(TH)
      DSDN(2,1) = SIN(TH)
      DSDN(3,1) = 0.0
C-----------------------------------------------------------------------
C     OUTPUT POSITION AND NORMAL
C-----------------------------------------------------------------------
C---AXIAL COMPONENT OF TANGENT
C
             DA = DSDN(1,1)
C
C---NORMAL COMPONENT OF TANGENT
C
             DN = DSDN(2,1)
C
C---ANGULAR LOCATION
C
           RADX = SQRT(RAM(2)**2 + RAM(3)**2)
            ANG = ASIN(RAM(3)/RADX)
C
           CANG = COS(ANG)
           SANG = SIN(ANG)
```

```
C
C---TANGENT 1 (AXIAL DIRECTION)
C
      DSDN(1,1) = DA
      DSDN(2,1) = DN*CANG
      DSDN(3,1) = DN*SANG
C
C---TANGENT 2 (CIRCUMFERENTIAL DIRECTION)
C
      DSDN(1,2) =  0.0
      DSDN(2,2) = -SANG
      DSDN(3,2) =  CANG
C
C---NORMAL
C
      CALL CROSS(DSDN(1,1),DSDN(1,2),SNORMAL(1,ISIDE),46)
C
C---POSITION
C
                      SIDE(1,ISIDE) = RAX
                      SIDE(2,ISIDE) = RAD*CANG
                      SIDE(3,ISIDE) = RAD*SANG
C
      IF(EPS3.EQ.1.0) THEN
C
                      SIDE(1,ISIDE) = E3(1)
                      SIDE(2,ISIDE) = E3(2)
                      SIDE(3,ISIDE) = E3(3)
C
                      END IF
C
      GO TO 1000
C-----------------------------------------------------------------------
C     DUCT SURFACE NEAR INLET                                   MAP = 7
C-----------------------------------------------------------------------
  700 IF(ISIDE.LT.4) THEN
C
C---SURFACE 1 AND 3
                     IEDG2 = LINE4
C
                      EPS1 = ETA(1)
                      EPS2 = ETA(2)
C
                     ELSE
C
C---SURFACE 5 AND 6
                     IEDG2 = LINE3
C
                      EPS1 = ETA(3)
                      EPS2 = ETA(2)
C
                     END IF
C
C---WELD REGION---------------------------------------------------------
C
           PI2 = 1.57079633
C
             B = COEFS(1,ISIDE) + EPS1*(COEFS(2,ISIDE) - COEFS(1,ISIDE))
C
          EPS3 = (COEFS(3,ISIDE) - 1.0)/(NMBRNDS(2) - 1.0)
```

```
C
                          RATIO = EPS2/EPS3
      IF(RATIO.GT.1.0) RATIO = 1.0
C
C---WELD RADIUS (RDOC) & DIFFERENCE BETWEEN HOLE AND DUCT RADIUS (DRHO)
C
      CALL DELRAD(B,RHO,DRHO,RHOD,RDOC)
C
C---CALCULATE AXIAL DISTANCE (CP)
C
      CALL CAXIS(B,RHO,CP)
C
         Y = RDOC - DRHO
C
       AAD = 0.5*((ABOT + ATOP) + (ATOP - ABOT)*COS(B - PI2))
         X = SQRT(DRHO*(2.0*RDOC - DRHO))
C
C---WELD ANGLE
C
       TH2 = ATAN(X/Y)
       TH1 = PI2 - TH2
C
        XX = AAD - X
C
       TH3 = ATAN(XX/RDOC)
C
      ANGL = RATIO*(TH2 + TH3) + TH1
C
C---POSITION AND TANGENT 1 (AXIAL DIRECTION)----------------------------
C
      IF(ANGL.GE.PI2) THEN
C
C---DUCT---------------------------------------
                               PSI = (ANGL - PI2)/TH3
C---AXIAL DISTANCE
                                CS = CP + X + PSI*XX
C---RADIUS
                                RS = RHOD
C---COORDINATES
                         CALL DUCT(B,RS,CS,SIDE(1,ISIDE))
C---TANGENT
                         DSDN(1,1) = DU1(1)
                         DSDN(2,1) = DU1(2)
                         DSDN(3,1) = DU1(3)
C---WELD---------------------------------------------
                         ELSE
C
                                XS = RDOC*COS(ANGL)
                                YS = RDOC*SIN(ANGL)
C---AXIAL DISTANCE
                                CS = CP + X - XS
C---RADIUS
                                RS = RHOD + RDOC - YS
C---COORDINATES
                         CALL DUCT(B,RS,CS,SIDE(1,ISIDE))
C---TANGENT
                              DXDN = TAN(ANGL)
C
                                CB = COS(B)
                                SB = SIN(B)
```

```
C
                    CALL VADD(CB,DU2,SB,DU3,VECTOR,DSDN(1,1))
C
                          ONE = 1.0
C
                    CALL VADD(DXDN,DU1,-ONE,VECTOR,C,DSDN(1,1))
C
                    END IF
C
C---DUCT REGION---------------------------------------------------------
C
      IF(RATIO.EQ.1.0) THEN
C
C---POSITION
                      PSI = (EPS2 - EPS3)/(1. - EPS3)
                     PSI1 = 1.0 - PSI
C
      CALL VADD(PSI1,SIDE(1,ISIDE),
     &           PSI,EDGE(1,IEDG2),SIDE(1,ISIDE),VECTOR)
C
C---TANGENT 1 (AXIAL DIRECTION) : INPUT
C
                     DSDN(1,1) = DU1(1)
                     DSDN(2,1) = DU1(2)
                     DSDN(3,1) = DU1(3)
C
                     END IF
C
C---TANGENT 2 (CIRCUMFERENTIAL DIRECTION)-------------------------------
C
             CB = COS(B)
             SB = SIN(B)
C
      CALL VADD(CB,DU2,SB,DU3,VECTOR,R1)
C
      CALL CROSS(DSDN(1,1),VECTOR,DSDN(1,2),47)
C
C---NORMAL
C
      CALL CROSS(DSDN(1,1),DSDN(1,2),SNORMAL(1,ISIDE),48)
C
C-----------------------------------------------------------------------
C   DIRECT SURFACE NORMAL INTO FLOW DOMAIN
C-----------------------------------------------------------------------
 1000 DO 1010 I=1,3
 1010 SNORMAL(I,ISIDE) = SNORMAL(I,ISIDE)*SIGNS(ISIDE)
C
          RETURN
C
C---FORMAT STATEMENTS
C
 1100 FORMAT(1H1,10X,20A4,13X,8H SECTION,I2,3H OF,I3,9H FOR ZONE,I3)
C
       END
C
C***********************************************************************
C*****OUTPUT************************************************************
C***********************************************************************
C
      SUBROUTINE BLKOUT(NUNIT,NODSTOR)
```

```
C----------------------------------------------------------------------
C   WRITES THE FORMATTED BLOCKED GEOMETRY FILE (NUNIT)
C----------------------------------------------------------------------
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /IOCOUNT/ IREWIND(40),NREAD(40),NWRITE(40)
      COMMON /MARCHS/  MARCH,INDEX(3)
      COMMON /OUT/     NODE(3,4000)
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
C
      IPLANE = NWRITE(NUNIT) + 1
C
                         WRITE(NUNIT,1000)  NODSTOR,IPLANE,
     &          NMBRNDS(1),NMBRNDS(2),NMBRNDS(3),MARCH
                         WRITE(NUNIT,1010) (NODE(1,I),I=1,NODSTOR)
                         WRITE(NUNIT,1010) (NODE(2,I),I=1,NODSTOR)
                         WRITE(NUNIT,1010) (NODE(3,I),I=1,NODSTOR)
C
   10 CONTINUE
C
   40 NWRITE(NUNIT) = NWRITE(NUNIT) + 1
C
      RETURN
C
C---FORMAT STATEMENTS
C
 1000 FORMAT(24I5)
 1010 FORMAT(6E22.14)
 1020 FORMAT(22I6)
C
      END
C
C**********************************************************************
C*****UTILITY**********************************************************
C**********************************************************************
C
      SUBROUTINE CROSS(A,B,C,N)
C----------------------------------------------------------------------
C   C = CROSS PRODUCT OF A AND B (UNIT VECTOR)
C----------------------------------------------------------------------
      COMMON /COUNTER/ NODESAV,NODETOT,NBNODES,NPLANE
      COMMON /HEADER/  ITITLE(20),LINE
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /UNITS/   NU5,NU6,NU20
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
C
      DIMENSION A(3),B(3),C(3)
C
C---CROSS PRODUCT
C
      C(1) = A(2)*B(3) - A(3)*B(2)
      C(2) = A(3)*B(1) - A(1)*B(3)
      C(3) = A(1)*B(2) - A(2)*B(1)
C
C---MAGNITUDE
C
      CALL VMAG(C,CMAG)
C
      IF(CMAG.GT.0.0) THEN
C
C---NORMALIZE
```

```
C
      C(1) = C(1)/CMAG
      C(2) = C(2)/CMAG
      C(3) = C(3)/CMAG
C
                      ELSE
      C(1) = 0.0
      C(2) = 0.0
      C(3) = 0.0
C
                      END IF
       RETURN
C
C---FORMAT STATEMENTS
C
 1000 FORMAT(1H1,10X,20A4,13X,8H SECTION,I2,3H OF,I3,9H FOR ZONE,I3)
 1010 FORMAT(9H LOCATION,I3,36H: CROSS PRODUCT EQUALS ZERO FOR NODE,I6)
C
      END
C
C***********************************************************************
C*****GRID SPACING******************************************************
C***********************************************************************
C
      SUBROUTINE ETABC(MARCH,INDEX,NODE)
C-----------------------------------------------------------------------
C   THIS ROUTINE SEPERATES THE BOUNDARY CONDITIONS AND
C   CALCULATES THE VALUE OF ETA.
C-----------------------------------------------------------------------
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /INITC/   PI,RADDEG
      COMMON /INPUTA/  EDGE(3,12),POINT(3,8),SIDE(3,6)
      COMMON /INPUTBC/ INODEBC(3),ISIDE(3)
      COMMON /SPACING/ ISTRTCH(3),STRETCH(3),ETAS(3,200),ETA(3),DETA(3)
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
C-----------------------------------------------------------------------
C   FIRST NODE
C-----------------------------------------------------------------------
      IF(NODE.EQ.1) THEN
C
                    ETA(INDEX) = 0.0
C
C---DETERMINE SIDE
C
                    ISIDE(INDEX) = 10 + (INDEX - 6)*INDEX
C
C---STORE SPACING
C
                    ETAS(INDEX,1) = 0.0
C
                    RETURN
C
                    END IF
C-----------------------------------------------------------------------
C   LAST NODE
C-----------------------------------------------------------------------
      IF(NODE.EQ.NMBRNDS(INDEX)) THEN
C
                                 ETA(INDEX) = 1.0
C
```

```
C---DETERMINE SIDE
C
                    ISIDE(INDEX) = 9 + (INDEX - 7)*INDEX/2
C
C---STORE SPACING
C
                                ETAS(INDEX,NODE) = 1.0
C
                                RETURN
C
                                END IF
C-----------------------------------------------------------------------
C   INTERIOR NODES
C-----------------------------------------------------------------------
       INODEBC(INDEX) = 9
C
      IF(ISECT.GT.1 .AND. INDEX.NE.MARCH) GO TO 310
C
C---CALCULATE ETA
C
                 ISTR = ISTRTCH(INDEX) + 1
C
      GO TO (100,110,120,130,140,150,160,170,180,190,200) ISTR
C
C---EQUAL SPACING----------------------------------------------------(0)
C
  100 ETA(INDEX) = ETA(INDEX) + DETA(INDEX)
C
      GO TO 300
C
C---INPUT ETA SPACING------------------------------------------------(1)
C
  110 ETA(INDEX) = ETAS(INDEX,NODE)
C
      GO TO 300
C
C---DECREASING SPACING; INPUT STRETCHING FACTOR----------------------(2)
C
  120       RATIO = REAL(NODE - 1)/REAL(NMBRNDS(INDEX) - 1)
C
               X1 = RATIO*STRETCH(INDEX)/2.0
             ETA1 = (EXP(X1) - EXP(-X1))/(EXP(X1) + EXP(-X1))
C
               X2 = STRETCH(INDEX)/2.0
             ETA2 = (EXP(X2) - EXP(-X2))/(EXP(X2) + EXP(-X2))
C
      ETA(INDEX) = ETA1/ETA2
C
      GO TO 300
C
C---INCREASING SPACING; INPUT STRETCHING FACTOR----------------------(3)
C
  130       RATIO = REAL(NMBRNDS(INDEX) - NODE)/REAL(NMBRNDS(INDEX) - 1)
C
               X1 = RATIO*STRETCH(INDEX)/2.0
             ETA1 = (EXP(X1) - EXP(-X1))/(EXP(X1) + EXP(-X1))
C
               X2 = STRETCH(INDEX)/2.0
             ETA2 = (EXP(X2) - EXP(-X2))/(EXP(X2) + EXP(-X2))
C
```

```
      ETA(INDEX) = 1.0 - ETA1/ETA2
C
      GO TO 300
C
C---DOUBLE STRETCHING; INPUT STRETCHING FACTOR----------------------(4)
C
  140          X1 = (STRETCH(INDEX)/2.0)/2.0
           ETAMID = (EXP(X1) - EXP(-X1))/(EXP(X1) + EXP(-X1))
C
            RATIO = REAL(NODE - 1)/REAL(NMBRNDS(INDEX) - 1)
C
               X2 = (RATIO - 0.5)*STRETCH(INDEX)/2.0
           ETAMAX = (EXP(X2) - EXP(-X2))/(EXP(X2) + EXP(-X2))
C
      ETA(INDEX) = (ETAMAX + ETAMID)/(2.0*ETAMID)
C
      GO TO 300
C
C---DECREASING SPACING; INPUT MINIMUM SPACING-----------------------(5)
C
  150        ARGI = STRETCH(INDEX)*REAL(NODE - 1)
             EXPI = EXP(ARGI)
            EXPII = 1.0/EXPI
            TANHI = (EXPI - EXPII)/(EXPI + EXPII)
C
             ARGN = STRETCH(INDEX)*REAL(NMBRNDS(INDEX) - 1)
             EXPN = EXP(ARGN)
            EXPNI = 1.0/EXPN
            TANHN = (EXPN - EXPNI)/(EXPN + EXPNI)
C
      ETA(INDEX) = TANHI/TANHN
C
      GO TO 300
C
C---INCREASING SPACING; INPUT MINIMUM SPACING-----------------------(6)
C
  160        ARGI = STRETCH(INDEX)*REAL(NMBRNDS(INDEX) - NODE)
             EXPI = EXP(ARGI)
            EXPII = 1.0/EXPI
            TANHI = (EXPI - EXPII)/(EXPI + EXPII)
C
             ARGN = STRETCH(INDEX)*REAL(NMBRNDS(INDEX) - 1)
             EXPN = EXP(ARGN)
            EXPNI = 1.0/EXPN
            TANHN = (EXPN - EXPNI)/(EXPN + EXPNI)
C
      ETA(INDEX) = 1.0 - TANHI/TANHN
C
      GO TO 300
C
C---DOUBLE STRETCHING; INPUT MINIMUM SPACING------------------------(7)
C
  170        ARGI = STRETCH(INDEX)*REAL(2*NODE - NMBRNDS(INDEX) - 1)
             EXPI = EXP(ARGI)
            EXPII = 1.0/EXPI
            TANHI = (EXPI - EXPII)/(EXPI + EXPII)
C
             ARGN = STRETCH(INDEX)*REAL(NMBRNDS(INDEX) - 1)
             EXPN = EXP(ARGN)
            EXPNI = 1.0/EXPN
```

```
            TANHN = (EXPN - EXPNI)/(EXPN + EXPNI)
C
      ETA(INDEX) = 0.5*(1.0 + TANHI/TANHN)
C
      GO TO 300
C
C---DECREASING SPACING; INPUT STRETCHING FACTOR----------------------(8)
C
  180       PIDN = PI/(STRETCH(INDEX)*NMBRNDS(INDEX))
C
      ETA(INDEX) = 1.0 - TAN(PIDN*(NMBRNDS(INDEX) - NODE))
     &                 /TAN(PIDN*(NMBRNDS(INDEX) - 1))
C
      GO TO 300
C
C---INCREASING SPACING; INPUT STRETCHING FACTOR----------------------(9)
C
  190       PIDN = PI/(STRETCH(INDEX)*NMBRNDS(INDEX))
C
      ETA(INDEX) = TAN(PIDN*(     NODE      - 1))
     &            /TAN(PIDN*(NMBRNDS(INDEX) - 1))
C
      GO TO 300
C
C---USER INPUT STRETCHING FUNCTION---------------------------------(10)
C
  200 CONTINUE
C
C---STORE SPACING---------------------------------------------------
C
  300 ETAS(INDEX,NODE) = ETA(INDEX)
C
  310       ETA(INDEX) = ETAS(INDEX,NODE)
C
      RETURN
      END
C
C*******************************************************************
C*****OUTPUT********************************************************
C*******************************************************************
C
      SUBROUTINE IOPACK(NUNIT)
C-------------------------------------------------------------------
C   GENERAL PURPOSE FORTRAN I/O PACKAGE FOR UNITS 1 -> 40
C-------------------------------------------------------------------
      COMMON /IOCOUNT/ IREWIND(40),NREAD(40),NWRITE(40)
      COMMON /UNITS/   NU5,NU6,NU20
C
      DATA IREWIND,NREAD,NWRITE /120*0/
C-------------------------------------------------------------------
C   ENTRY RWIND: REWIND FILE ON NUNIT
C-------------------------------------------------------------------
      ENTRY RWIND(NUNIT)
C
      IREWIND(NUNIT) = 1
C
      REWIND NUNIT
C
      RETURN
C-------------------------------------------------------------------
```

```
C   ENTRY STATUS: PRINT STATUS OF I/O OPERATIONS ON ALL UNITS
C-----------------------------------------------------------------------
      ENTRY STATUS(NUNIT)
C
      WRITE(NU6,1000)
C
      DO 10 NU=1,40
   10 IF(IREWIND(NU).EQ.1) WRITE(NU6,1010) NU,NREAD(NU),NWRITE(NU)
C
      RETURN
C
C---FORMAT STATEMENTS
C
 1000 FORMAT(//42X,38H STATUS OF I/O OPERATIONS ON ALL UNITS
     1         //42X,32H        UNIT      NO. OF    NO. OF .
     2          /42X,32H       NUMBER     READS     WRITES / )
 1010 FORMAT(42X,3I10)
C
      END
C
C***********************************************************************
C*****OUTPUT************************************************************
C***********************************************************************
C
      SUBROUTINE OUTPUT(NUNIT,NODSTOR)
C-----------------------------------------------------------------------
C   PRINTOUT AND STORE DATA
C-----------------------------------------------------------------------
C
      COMMON /COUNTER/ NODESAV,NODETOT,NBNODES,NPLANE
      COMMON /HEADER/  ITITLE(20),LINE
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /OUT/     NODE(3,4000)
      COMMON /UNITS/   NU5,NU6,NU20
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
C
C---TOTAL NUMBER OF PLANES
C
            NPLANE = NPLANE + 1
C
C---PRINT NODAL INFORMATION--------------------------------------------
C
        IPRINT = 1
C
      NODETOT = NODSTOR + NODETOT
      NODESAV = NODESAV - NODSTOR
C
C---PRINT TOTAL NUMBER OF POINTS STORED--------------------------------
C
          LINE = LINE + 3
C
       IF(LINE.GE.60) THEN
C
                         WRITE(NU6,1000) ITITLE,IZONE
                         WRITE(NU6,1030)
C
                         LINE = 7
C
                         END IF
C
```

```
      WRITE(NU6,1060) NODSTOR,NPLANE,NUNIT,NODETOT
C
C---------------------------------------------------------------------
C   STORE OUTPUT
C---------------------------------------------------------------------
  200 CALL BLKOUT(NUNIT,NODSTOR)
C
      RETURN
C
C---FORMAT STATEMENTS
C
 1000 FORMAT(1H1,10X,20A4,13X,8H SECTION,I2,3H OF,I3,9H FOR ZONE,I3)
 1020 FORMAT(1X,I6,2(1X,F13.7),5X,F7.2,6X,F7.2,5X,I2)
 1030 FORMAT( / 44H   NODE         X              Y              Z   )
 1040 FORMAT(1X,I6,3(1X,F13.7),2X,2(2X,F7.2),F11.3,3X,2(2X,F7.2),5X,I2)
 1050 FORMAT(/  5X,I5,18H POINTS FROM PLANE,I4,15H STORED ON UNIT,I3,
     &                 23H: TOTAL POINTS STORED =,I6 / )
 1060 FORMAT(/ 10X,I5,18H POINTS FROM PLANE,I4,15H STORED ON UNIT,I3,
     &                 23H: TOTAL POINTS STORED =,I6 / )
C
      END
C
C*********************************************************************
C*****OUTPUT**********************************************************
C*********************************************************************
C
      SUBROUTINE PICTURE(IDRAW)
C---------------------------------------------------------------------
C   THIS ROUTINE DESCRIBES THE NOMENCLATURE
C---------------------------------------------------------------------
      COMMON /UNITS/   NU5,NU6,NU20
C
      WRITE(NU6,300)
      WRITE(NU6,310)
      WRITE(NU6,320)
      WRITE(NU6,330)
C
      RETURN
C
C---FORMAT STATEMENTS
C
  300 FORMAT( 40X,37H                          NOMENCLATURE
     1        /40X,19H                IE
     2        /40X,19H                IT
     3        /40X,34H                IA      SURFACE 4
     4        /40X,32H                I2        (TOP)
     5        /40X,50H           POINT 4  I                        POINT 3
     6        /40X,42H                O-----------------------O
     7        /40X,42H               8/I        EDGE 3      7/I
     8        /40X,50H              E/ I                   E/ I        S)
  310 FORMAT( 40X,50H             G/  I     SURFACE 1    G/  I        U
     1        /40X,50H            D/   I      (BACK)     D/   I    E   R
     2        /40X,50H           E/    EI                E/    I    D   F
     3        /40X,50H POINT 8  O-----DI-----------------O POINT 7 G   A
     4        /40X,50H          I      GI    EDGE 11     I     I    E   C
     5        /40X,50H     S    I      EI                IE    I        E
     6        /40X,46H     U   E I      I                ID    I    2
     7        /40X,50H     R   D I     4I     SURFACE 3   IG    I        6
     8        /40X,42H     F   G I      I      (FRONT)    IE    I
     9        /40X,50H     A   E I      O_________________I_____O____ETA1)
```

```
 320 FORMAT( 40X,51H   C    POINT 1 /5      EDGE 1     I1    /  POINT 2
    1        /40X,42H   E   1  I    /E                  I0    /6
    2        /40X,41H       2  I   /G                   I   /E
    3        /40X,40H   5      I  /D                    I  /G
    4        /40X,39H          I /E                     I /D
    5        /40X,38H          O/_______________________O/E
    6        /40X,44H   POINT 5         EDGE 9            POINT 6
    7        /40X,10H         /
    8        /40X,26H        /3        SURFACE 2
    9        /40X,25H       /A         (BOTTOM)                    )
 330 FORMAT( 40X, 8H      /T
    &        /40X, 7H     /E                                      )
C
C-------------------123456789012345678901234567890123456789012345678901
C
      END
C
C*********************************************************************
C*****UTILITY*********************************************************
C*********************************************************************
C
      SUBROUTINE VADD(CA,A,CB,B,C,UC)
C---------------------------------------------------------------------
C   VADD COMPUTES C,THE SUM OF VECTORS CA*A AND CB*B,WHERE CA AND
C   CB ARE SCALARS. UC IS A UNIT VECTOR DIRECTED ALONG C.
C---------------------------------------------------------------------
C
      DIMENSION A(3),B(3),C(3),UC(3)
C
      SUM = 0.0
C
      DO 10 I=1,3
      C(I) = CA*A(I) + CB*B(I)
   10  SUM = SUM + C(I)*C(I)
C
      CMAG = SQRT(SUM)
C
                       RMAG = 0.0
      IF(CMAG.GT.0.0) RMAG = 1.0/CMAG
C
      UC(1) = C(1)*RMAG
      UC(2) = C(2)*RMAG
      UC(3) = C(3)*RMAG
C
      RETURN
      END
C
C*********************************************************************
C*****UTILITY*********************************************************
C*********************************************************************
C
      SUBROUTINE VDOT(A,B,C)
C---------------------------------------------------------------------
C   VDOT COMPUTES C,THE DOT PRODUCT OF VECTORS A AND B.
C---------------------------------------------------------------------
C
      DIMENSION A(3),B(3)
C
      C = 0.0
C
```

```
      DO 10 I=1,3
   10 C = C + A(I)*B(I)
C
      RETURN
      END
C
C***********************************************************************
C*****UTILITY***********************************************************
C***********************************************************************
C
      SUBROUTINE VMAG(VECTOR,VECMAG)
C-----------------------------------------------------------------------
C   VMAG DETERMINES THE MAGNITUDE OF A VECTOR
C-----------------------------------------------------------------------
C
      DIMENSION VECTOR(3)
C
      VECMAG = SQRT(VECTOR(1)**2 + VECTOR(2)**2 + VECTOR(3)**2)
C
      IF(VECMAG.LT.0.0000001) VECMAG = 0.0
C
      RETURN
      END
C
C***********************************************************************
C*****HGM_2*************************************************************
C***********************************************************************
C
      SUBROUTINE CAXIS(B,RHO,C)
C-----------------------------------------------------------------------
C     CALCULATE AXIAL DISTANCE CORRESPONDING TO A POINT ON THE HOLE.
C
C     B      ANGULAR LOCATION OF POINT ON THE HOLE
C     C      AXIAL DISTANCE
C     RHO    HOLE RADIUS
C-----------------------------------------------------------------------
C
      COMMON /DFN1/  DU1(3),DU2(3),DU3(3),DFNB,DFND,DFNF
      COMMON /DFN2/  AE,BE,DFNR,ZSTAR,AGL,BETA1,BETA2,BETA3,BETA4
      COMMON /INITC/ PI,RADDEG
C
C---TOLERANCE FOR NEWTON-RAPHSON ITERATION
C
       FEPS = 1.0E-07
C
C---ANGLE OF DUCT AXIS
C
         SA = SIN(AGL)
         CA = COS(AGL)
C
C---ANGLULAR LOCATION OF A POINT ON THE HOLE
C
         SB = SIN(B)
         CB = COS(B)
C
C---AXIAL DISTANCE ALONG LOWER EDGE OF DUCT
C
      DELTA = 0.0/RADDEG
C
      IF((B.GE.(BETA4 - DELTA)) .AND. (B.LE.BETA3)) THEN
```

```
C
                                                   C = (ZSTAR + RHO*SA*CB)/CA
C
                                                            RETURN
C
                                                            END IF
C
C---DISTANCE ALONG MAJOR AXIS OF BOWL ELLIPSE
C
                         XT = DFNF - DFND + RHO*CB
      IF(ABS(XT).GT.AE) XT = AE
C
C---VERTICAL DISTANCE TO HOLE
C
         YT = DFNB + RHO*SB
C
C---DISTANCE ALONG MINOR AXIS OF BOWL ELLIPSE
C
         DR = SQRT(AE**2 - XT**2)*BE/AE
C
C---INITIAL DUCT AXIAL DISTANCE
C
          C = SQRT((DFNR + DR)**2 - YT**2)
C
C---NEWTON-RAPHSON ITERATION------------------------------------------
C
   10   XTT = DFNF - DFND + C*SA + RHO*CA*CB
        YTT = YT
        ZTT = C*CA - RHO*SA*CB
C
C---FUNCTION
C
         DR = SQRT(AE**2 - XTT**2)*BE/AE
         FC = (DFNR + DR)**2 - YTT**2 - ZTT**2
C
C---DERIVATIVE
C
      DFDC1 =  XTT*SA*(DFNR + DR)*BE/AE
      DFDC2 =  DR*AE/BE
      DFDC3 =  ZTT*CA
       DFDC = -2.*(DFDC1/DFDC2 + DFDC3)
C
C---DUCT AXIAL DISTANCE
C
          C = C - FC/DFDC
C
      IF(ABS(FC).GT.FEPS) GO TO 10
C
      RETURN
      END
C
C***********************************************************************
C*****HGM 2*************************************************************
C***********************************************************************
C
      SUBROUTINE DCTDAT
C-----------------------------------------------------------------------
C     DATA DESCRIBING HOLE AND WELD RADIUS
C-----------------------------------------------------------------------
C
```

```
      COMMON /DFN3/ AD,BD,BETA(37),DELRHO(37),RADOC(37)
C
      DIMENSION DCT1(37),DCT2(37),DCT3(37)
C
      DATA RADDEG/57.29577951/
C
C---ANGULAR INCREMENT AROUND HOLE
C
C
C---DIFFERENCE IN RADIUS BETWEEN DUCT AND HOLE
C
C
C---RADIUS OF CURVATURE OF FAIRING
C
C
C---READ DUCT DATA
C
      READ(5,1000) (DCT1(I),I=1,37)
C
      READ(5,1000) (DCT2(I),I=1,37)
C
      READ(5,1000) (DCT3(I),I=1,37)
C
C---CONVERT DEGREES TO RADIANS AND INCHES TO FEET
C
      DO 10 I = 1,37
C
        BETA(I) = DCT1(I) / RADDEG
      DELRHO(I) = DCT2(I)
   10  RADOC(I) = DCT3(I)
C
C---FORMAT STATEMENT
C
 1000 FORMAT((8F10.3))
C
      RETURN
      END
C
C***********************************************************************
C*****HGM_2*************************************************************
C***********************************************************************
C
      SUBROUTINE DELRAD(B,RHO,DRHO,RHOD,RDOC)
C-----------------------------------------------------------------------
C     INTERPOLATES HOLE RADIUS, WELD RADIUS, DUCT RADIUS, AND DIFFERENCE
C     BETWEEN HOLE AND DUCT RADIUS FOR POINTS BETWEEN ANGULAR INCREMENTS.
C
C      B       ANGULAR LOCATION OF POINT ON HOLE
C      RHO     HOLE RADIUS
C      RHOD    DUCT RADIUS
C      RDOC    WELD RADIUS
C      DRHO    DIFFERENCE BETWEEN HOLE AND DUCT RADIUS
C-----------------------------------------------------------------------
C
      COMMON /DFN3/ AD,BD,BETA(37),DELRHO(37),RADOC(37)
C
C---ANGULAR LOCATION OF A POINT ON THE DUCT
C
                    BB = B
      IF(B.LT.0.0) BB = 6.283185308 + B
```

```
C
C---BRACKET ANGULAR INCREMENT
C
      DO 10 I = 1,36
C
      DBK = BETA(I+1) - BETA(I)
       DB = BB - BETA(I)
C
      IF(DB.LE.DBK) THEN
C
C---INTERPOLATE-----------------------------------------------------------
C
C---SEGMENT RATIO
                         PSI = DB/DBK
C
C---DIFFERENCE IN RADIUS BETWEEN DUCT AND HOLE
C
                        DRHO = DELRHO(I)*(1. - PSI) + DELRHO(I+1)*PSI
C
C---RADIUS OF WELD
C
                        RDOC =  RADOC(I)*(1. - PSI) +  RADOC(I+1)*PSI
C
C---RADIUS OF DUCT ELLIPSE
C
                        CBSQ = COS(B)**2
                        SBSQ = SIN(B)**2
C
                        RADX = SQRT(SBSQ*AD*AD + CBSQ*BD*BD)
                        RHOD = AD*BD/RADX
C
C---HOLE RADIUS
C
                         RHO = RHOD + DRHO
C
                        RETURN
C
                        END IF
   10 CONTINUE
C
      RETURN
      END
C
C***********************************************************************
C*****HGM 2*************************************************************
C***********************************************************************
C
      SUBROUTINE DERIV(B,RHO,C,DRDB,DCDB)
C-----------------------------------------------------------------------
C     COMPUTE DRDB,DCDB
C-----------------------------------------------------------------------
C
      COMMON /DFN1/ DU1(3),DU2(3),DU3(3),DFNB,DFND,DFNF
      COMMON /DFN2/ AE,BE,DFNR,ZSTAR,AGL,BETA1,BETA2,BETA3,BETA4
      COMMON /DFN3/ AD,BD,BETA(37),DELRHO(37),RADOC(37)
C
C---POINT ANGLE
C
         CB = COS(B)
         SB = SIN(B)
```

```
C
        EX1 = BD**2 - AD**2
        EX2 = ((AD*SB)**2 + (BD*CB)**2)**1.5
      DRDDB = EX1*AD*BD*SB*CB/EX2
C
C---BRACKET BETA
C
      DO 10 I = 1,36
C
      DBI = BETA(I+1) - BETA(I)
       DB = B - BETA(I)
       IB = I
C
      IF(DB.LE.DBI) GO TO 20
C
   10 CONTINUE
   20 CONTINUE
C
      DDRO = (DELRHO(IB+1) - DELRHO(IB))/(BETA(IB+1) - BETA(IB))
C
      DRDB = DRDDB + DDRO
C
C---FOR BETA BETWEEN BETA4 AND BETA3
C
      IF((B.GE.BETA4).AND.(B.LE.BETA3)) THEN
C
                                   DCDB = (DRDB*CB-RHO*SB)*TAN(AGL)
C
                                   RETURN
C
                                   END IF
C
C---AXIS ANGLE
C
        CA = COS(AGL)
        SA = SIN(AGL)
C
       XMD = DFNF - DFND + C*SA + RHO*CA*CB
      EXR1 = BE/AE
      EXR2 = SQRT(AE**2 - XMD**2)
       EXR = (DFNR + EXR1*EXR2)*XMD*EXR1/EXR2
C
      EXC1 = C*CA - RHO*SA*CB
      EXC2 = RHO*CB + DRDB*SB
      EXC3 = DRDB*CB - RHO*SB
      EXC4 = DFNB + RHO*SB
      EXCN = (EXC1*SA - EXR*CA)*EXC3 - EXC2*EXC4
      EXCD = EXR*SA + EXC1*CA
      DCDB = EXCN/EXCD
C
      RETURN
      END
C
C**********************************************************************
C*****HGM_2************************************************************
C**********************************************************************
C
      SUBROUTINE DEXIT(B,POINT,DE)
C----------------------------------------------------------------------
C     COMPUTE POINT COORDINATES ON DUCT EXIT PLANE
```

```
C
C      AGL    ANGLE OF DUCT AXIS
C        B    ANGLE OF POINT
C       AD    ELLIPSE MINOR AXIS (HORIZONTAL)
C       BD    ELLIPSE MAJOR AXIS (VERTICAL)
C       CQ    AXIAL DISTANCE TO POINT ON DUCT EXIT NORMAL IN X_Z PLANE
C       CE    AXIAL DISTANCE TO POINT ON AXIS OF DUCT EXIT
C     DFNB    VERTICAL DISTANCE TO AXIS ORIGIN
C     DFNF    AXIAL DISTANCE TO AXIS ORIGIN
C-----------------------------------------------------------------------
C
      COMMON /DFN1/ DU1(3),DU2(3),DU3(3),DFNB,DFND,DFNF
      COMMON /DFN2/ AE,BE,DFNR,ZSTAR,AGL,BETA1,BETA2,BETA3,BETA4
      COMMON /DFN3/ AD,BD,BETA(37),DELRHO(37),RADOC(37)
      COMMON /DFN5/ CE,CQ,ABOT,ATOP
C
      DIMENSION POINT(6)
C
C---AXIS ANGLE
C
           COA = COS(AGL)
           SIA = SIN(AGL)
C
C---POINT ANGLE
C
           COB = COS(B)
           SIB = SIN(B)
C
C---RADIUS OF ELLIPTIC DUCT
C
          RADX = SQRT((AD*SIB)**2 + (BD*COB)**2)
          RHOD = AD*BD/RADX
C
C---AXIAL DISTANCE
C
             C = CE + RHOD*SIB*DFNB/(CQ - CE)
C
C---COORDINATES
C
      POINT(1) = DFNF + C*SIA + RHOD*COA*COB
      POINT(2) = DFNB         + RHOD*SIB
      POINT(3) =        C*COA - RHOD*SIA*COB
C
      RETURN
      END
C
C***********************************************************************
C*****HGM_2*************************************************************
C***********************************************************************
C
      SUBROUTINE HGMIN
C-----------------------------------------------------------------------
C     INPUT FOR TWO DUCT HGM WITH TURN AROUND DUCT
C-----------------------------------------------------------------------
C
      COMMON /COEFF/   COEFE(8,10,12),COEFS(8,6),NMBRSEG(12)
      COMMON /INITA/   IZINDEX,MAPTEN,INCHES
      COMMON /INITC/   PI,RADDEG
      COMMON /INPUTA/  EDGE(3,12),POINT(3,8),SIDE(3,6)
      COMMON /MAPING/  MAPSIDE(6),MAPSEG(10,12)
```

```
      COMMON /MAXIMUM/ ETAMAX(10,12),SEGMAX(3,10,12)
      COMMON /ZONING/  IZONE,ISECT,NZINDEX,NMBRNDS(3)
C
      COMMON /DFN1/ DU1(3),DU2(3),DU3(3),DFNB,DFND,DFNF
      COMMON /DFN2/ AE,BE,DFNR,ZSTAR,AGL,BETA1,BETA2,BETA3,BETA4
      COMMON /DFN3/ AD,BD,BETA(37),DELRHO(37),RADOC(37)
      COMMON /DFN4/ IHOLE,PL(6,6,4),PA(2,6,4),EDG(6,4)
      COMMON /DFN5/ CE,CQ,ABOT,ATOP
      COMMON /DFN6/ RTADI,RTADO,RCI,RCO,RDI,RDO,XCI,XCO,XTADI,XTADO
      COMMON /DFN7/ RWO21,XWO21,RADII,RADIO
C
      DIMENSION CADD(3),VEC(3),VDUM(3),UE(3)
C-----------------------------------------------------------------------
C     GENERAL CONSTANTS
C-----------------------------------------------------------------------
                IHOLE = 0
C
C---BOWL ELLIPSE--------------------------------------------------------
C
                   AE = 4.5
                   BE = 2.85776
C
C---ORIGIN OF BOWL ELLIPSE
C
                 DFND = 5.5
                 DFNR = 6.02472
C
C---BOWL ELLIPSE FOCI
C
                   FE = SQRT(AE*AE - BE*BE)
C
C---FIRST BOWL ELLIPSE FOCI AXIAL DISTANCE
C
                  XFE = DFND - FE
C
C---ANGLES OF POINTS ON HOLE--------------------------------------------
C
                BETA1 = 130./RADDEG
                BETA2 =  50./RADDEG
                BETA3 = 298./RADDEG
                BETA4 = 220./RADDEG
C
C---ORIGIN OF DUCT AXIS-------------------------------------------------
C
                 DFNB = 5.0
                 DFNF = 5.2
C
C---ANGLE OF DUCT
C
                  AGL = 10.0/RADDEG
C
C---UNIT VECTORS OF DUCT COORDINATE SYSTEM
C
               DU1(1) =  SIN(AGL)
               DU1(2) =  0.
               DU1(3) =  COS(AGL)
C
               DU2(1) =  COS(AGL)
               DU2(2) =  0.
               DU2(3) = -SIN(AGL)
```

```
C
                 DU3(1) =  0.
                 DU3(2) =  1.
                 DU3(3) =  0.
C
C---DUCT ELLIPSE
C
                     AD = 2.98
                     BD = 3.55
C
C---AXIAL LENGTH TO DUCT EXIT PLANE  .
C
                     CE = 16.2
C
C---AXIAL LENGTH TO POINT ON EXIT PLANE NORMAL IN X-Z PLANE
C
                     CQ = 25.206
C
C---UNKNOWN
C
                   ATOP = 7.
                   ABOT = 3.
C
C---POINT 1: BOWL ENTRANCE - INNER---------------------------------------
C
                  RADII = 6.6
C
C---POINT 2: END OF BOWL - INNER
C
                    XLI = 9.810
C
                  RADOI = 6.029
C
C---POINT 3: END OF BOWL - OUTER
C
                    XLO = 9.830
C
                    CXL = ((XLO - DFND)/AE)**2
C
                  RADOO = DFNR + BE*SQRT(1.0 - CXL)
C
C---POINT 4: BOWL ENTRANCE - OUTER
C
                  RADIO = 7.5
C
C---EDGE 1: SEGMAX 1-----------------------------------------------------
C
                 XMAX11 = 2.450
C
C---EDGE 1: SEGMAX 3
C
                 XMAX31 = 7.912
                 RMAX31 = 6.380
C
C---EDGE 3: SEGMAX 1
C
                 XMAX13 = 1.0
                 RMAX13 = 7.815
C
                  ZSTAR = RMAX13
```

```
C
C---EDGE 3: SEGMAX 2
C
                 CR23 = ((RMAX13 - DFNR)/BE)**2
C
               XMAX23 = DFND - AE*SQRT(1.0 - CR23)
C
C---EDGE 3: SEGMAX 3
C
C               XMAX33 = 3.0
               XMAX33 = 2.35
C
C---EDGE 3: SEGMAX 4
C
               XMAX43 = DFND + AE*SQRT(1.0 - CR23)
C
C---EDGE 11: SEGMAX 3
C
              XMAX311 = 3.4
C
                CX311 = ((XMAX311 - DFND)/AE)**2
C
              RMAX311 = DFNR + BE*SQRT(1.0 - CX311)
C
C---EDGE 11: SEGMAX 4
C
              XMAX411 = 8.5
C
                CX411 = ((XMAX411 - DFND)/AE)**2
C
              RMAX411 = DFNR + BE*SQRT(1.0 - CX411)
C
C---ANGLE OF INTERSECTION BETWEEN SECTION 1 AND SECTION 2---------------
C
               THETAD = 75.0
C
                   TH = THETAD/RADDEG
                  CTH = COS(TH)
                  STH = SIN(TH)
C
C---ANGLE OF INTERSECTION FOR SEGMENT 1 & 2 AND SEGMENT 2 & 3-----------
C
              THETAD2 = 18.0
C
                 THE2 = THETAD2/RADDEG
                CTHE2 = COS(THE2)
                STHE2 = SIN(THE2)
C
              THETAD3 = 82.0
C
                 THE3 = THETAD3/RADDEG
                CTHE3 = COS(THE3)
                STHE3 = SIN(THE3)
C
      IF(IZONE.EQ.1.AND.IZINDEX.GT.1)THEN
        GO TO 40
      ELSE
        GO TO 50
      END IF
C
```

```
   40   GO TO (50,50,200,300,300,50) IZINDEX
C
   50 IF(IZONE.GT.1) GO TO 100
C
C*************************************************************************
C     ZONE 1 - (SIDE OF BOWL WITHOUT HOLE)
C*************************************************************************
C---EDGE COEFFICIENTS-------------------------------------------------------
C
C---EDGE 3: ELLIPSE
C
        COEFE(1,3,3) =  XFE
        COEFE(3,3,3) = -DFNR
        COEFE(4,3,3) =  1.0
C
C---EDGE 5: CIRCULAR ARC
C
        COEFE(1,1,5) =  0.0
        COEFE(4,1,5) =  1.0
C
C---EDGE 6: CIRCULAR ARC
C
        COEFE(1,1,6) =  XLI
        COEFE(4,1,6) =  1.0
C
C---EDGE 7: CIRCULAR ARC
C
        COEFE(1,1,7) =  XLO
        COEFE(4,1,7) =  1.0
C
C---EDGE 8: CIRCULAR ARC
C
        COEFE(1,1,8) =  0.0
        COEFE(4,1,8) =  1.0
C
C---EDGE 11: ELLIPSE
C
      DO 10 K = 3,5
C
       COEFE(1,K,11) =  XFE
       COEFE(2,K,11) =  DFNR*STH
       COEFE(3,K,11) = -DFNR*CTH
   10  COEFE(4,K,11) =  1.0
C
C---SURFACE COEFFICIENTS---------------------------------------------------
C
          COEFS(4,2) = 1.0
          COEFS(7,2) = 3.0
C
          COEFS(4,4) = 1.0
          COEFS(7,4) = 3.0
C
          COEFS(4,6) = 1.0
          COEFS(7,6) = 3.0
C
C---CORNER POINT COORDINATES ---------------------------------------------
C
          POINT(1,1) =  0.0
          POINT(2,1) =  0.0
          POINT(3,1) = -RADII
```

```
C
          POINT(1,2) =  XLI
          POINT(2,2) =  0.0
          POINT(3,2) = -RADOI
C
          POINT(1,3) =  XLO
          POINT(2,3) =  0.0
          POINT(3,3) = -RADOO
C
          POINT(1,4) =  0.0
          POINT(2,4) =  0.0
          POINT(3,4) = -RADIO
C
          POINT(1,5) =  0.0
          POINT(2,5) =  RADII*STH
          POINT(3,5) = -RADII*CTH
C
          POINT(1,6) =  XLI
          POINT(2,6) =  RADOI*STH
          POINT(3,6) = -RADOI*CTH
C
          POINT(1,7) =  XLO
          POINT(2,7) =  RADOO*STH
          POINT(3,7) = -RADOO*CTH
C
          POINT(1,8) =  0.0
          POINT(2,8) =  RADIO*STH
          POINT(3,8) = -RADIO*CTH
C
C---EDGE SEGMENT COORDINATES ---------------------------------------
C
      SEGMAX(1,1, 1) =  XMAX11
      SEGMAX(3,1, 1) = -RADII
C
      SEGMAX(1,2, 1) =  XMAX31
      SEGMAX(3,2, 1) = -RMAX31
C
      SEGMAX(1,1, 3) =  XMAX13
      SEGMAX(3,1, 3) = -RMAX13
C
      SEGMAX(1,2, 3) =  XMAX23
      SEGMAX(3,2, 3) = -RMAX13
C
      SEGMAX(1,1, 9) =  XMAX11
      SEGMAX(2,1, 9) =  RADII*STH
      SEGMAX(3,1, 9) = -RADII*CTH
C
      SEGMAX(1,2, 9) =  XMAX31
      SEGMAX(2,2, 9) =  RMAX31*STH
      SEGMAX(3,2, 9) = -RMAX31*CTH
C
      SEGMAX(1,1,11) =  XMAX13
      SEGMAX(2,1,11) =  RMAX13*STH
      SEGMAX(3,1,11) = -RMAX13*CTH
C
      SEGMAX(1,2,11) =  XMAX23
      SEGMAX(2,2,11) =  RMAX13*STH
      SEGMAX(3,2,11) = -RMAX13*CTH
C
      SEGMAX(1,3,11) =  XMAX311
```

```
      SEGMAX(2,3,11) =  RMAX311*STH
      SEGMAX(3,3,11) = -RMAX311*CTH
C
      SEGMAX(1,4,11) =  XMAX411
      SEGMAX(2,4,11) =  RMAX411*STH
      SEGMAX(3,4,11) = -RMAX411*CTH
C
C---EDGE NODE DISTRIBUTION------------------------------------------------
C
        ETAMAX(1, 1) = 12.0
        ETAMAX(2, 1) = 44.0
C
        ETAMAX(1, 3) =  5.0
        ETAMAX(2, 3) = 10.0
C
        ETAMAX(1, 9) = 12.0
        ETAMAX(2, 9) = 44.0
C
        ETAMAX(1,11) =  5.0
        ETAMAX(2,11) = 10.0
        ETAMAX(3,11) = 19.0
        ETAMAX(4,11) = 48.0
C
       RETURN
C
C***********************************************************************
C     ZONE 2 - (SIDE OF BOWL WITH HOLE)
C***********************************************************************
  100 IF(IZONE.GT.2)GO TO 200
C
C---EDGE COEFFICIENTS----------------------------------------------------
C
C---EDGE 3: ELLIPSE
C
       DO 110 K = 3,5
C
       COEFE(1,K, 3) =  XFE
       COEFE(2,K, 3) =  DFNR*STH
       COEFE(3,K, 3) = -DFNR*CTH
  110  COEFE(4,K, 3) =  1.0
C
C---EDGE 5: CIRCULAR ARC
C
       COEFE(1,1, 5) = 0.0
       COEFE(4,1, 5) = 1.0
C
C       COEFE(1,2, 5) = 0.0
C       COEFE(4,2, 5) = 1.0
C
C       COEFE(1,3, 5) = 0.0
C       COEFE(4,3, 5) = 1.0
C
C---EDGE 6: CIRCULAR ARC
C
       COEFE(1,1, 6) = XLI
       COEFE(4,1, 6) = 1.0
C
C       COEFE(1,2, 6) = XLI
C       COEFE(4,2, 6) = 1.0
C
```

```
C       COEFE(1,3, 6) = XLI
C       COEFE(4,3, 6) = 1.0
C
C---EDGE 7: CIRCULAR ARC
C
      COEFE(1,1, 7) = XLO
      COEFE(4,1, 7) = 1.0
C
      COEFE(1,2, 7) = XLO
      COEFE(4,2, 7) = 1.0
C
      COEFE(1,3, 7) = XLO
      COEFE(4,3, 7) = 1.0
C
C---EDGE 8: CIRCULAR ARC
C
      COEFE(1,1, 8) = 0.0
      COEFE(4,1, 8) = 1.0
C
      COEFE(4,2, 8) = 1.0
      COEFE(4,3, 8) = 1.0
C
C---EDGE 11: ELLIPSE
C
      COEFE(1,3,11) = 0.0
      COEFE(2,3,11) = 0.0
      COEFE(3,3,11) = 0.0
      COEFE(4,3,11) = 0.0
C
      COEFE(1,4,11) = 0.0
      COEFE(2,4,11) = 0.0
      COEFE(3,4,11) = 0.0
      COEFE(4,4,11) = 0.0
C
      COEFE(1,5,11) = XFE
      COEFE(2,5,11) = 0.0
      COEFE(3,5,11) = DFNR
      COEFE(4,5,11) = 1.0
C
C---SURFACE COEFFICIENTS---------------------------------------------
C
          COEFS(4,2) = 1.0
          COEFS(7,2) = 3.0
C
          COEFS(4,6) = 1.0
          COEFS(7,6) = 3.0
C
C---CORNER POINT COORDINATES-----------------------------------------
C
          POINT(1,1) =  0.0
          POINT(2,1) =  RADII*STH
          POINT(3,1) = -RADII*CTH
          POINT(4,1) =  0.0
          POINT(5,1) =  0.0
C
          POINT(1,2) =  XLI
          POINT(2,2) =  RADOI*STH
          POINT(3,2) = -RADOI*CTH
          POINT(4,2) =  THETAF
          POINT(5,2) =  90.0
```

```
C
          POINT(1,3) =  XLO
          POINT(2,3) =  RADOO*STH
          POINT(3,3) = -RADOO*CTH
          POINT(4,3) =  THETAF
          POINT(5,3) =  90.0
C
          POINT(1,4) =  0.0
          POINT(2,4) =  RADIO*STH
          POINT(3,4) = -RADIO*CTH
          POINT(4,4) =  12.831
          POINT(5,4) = - 7.491
C
          POINT(1,5) = 0.0
          POINT(2,5) = 0.0
          POINT(3,5) = RADII
          POINT(4,5) = 0.0
          POINT(5,5) = 0.0
C
          POINT(1,6) = XLI
          POINT(2,6) = 0.0
          POINT(3,6) = RADOI
          POINT(4,6) = 0.0
          POINT(5,6) = 0.0
C
          POINT(1,7) = XLO
          POINT(2,7) = 0.0
          POINT(3,7) = RADOO
          POINT(4,7) = 0.0
          POINT(5,7) = -50.0
C
          POINT(1,8) = 0.0
          POINT(2,8) = 0.0
          POINT(3,8) = RADIO
          POINT(4,8) = 0.0
          POINT(5,8) = 14.7
C
C---UPPER LEFT CORNER ON HOLE-------------------------------------------
C
      CALL HOLE(BETA1,EDG(1,1),VDUM)
C
              RAD1 = SQRT(EDG(2,1)**2 + EDG(3,1)**2)
              ANG1 = ACOS(EDG(2,1)/RAD1)
C
C---UPPER RIGHT CORNER ON HOLE
C
      CALL HOLE(BETA2,EDG(1,2),VDUM)
C
              RAD2 = SQRT(EDG(2,2)**2 + EDG(3,2)**2)
              ANG2 = ACOS(EDG(2,2)/RAD2)
C
C---LOWER RIGHT CORNER ON HOLE
C
      CALL RHOS(BETA(31),DELRHO(31))
C
      CALL HOLE(BETA3,EDG(1,3),VDUM)
C
              RAD3 = SQRT(EDG(2,3)**2 + EDG(3,3)**2)
              ANG3 = ACOS(EDG(2,3)/RAD3)
C
```

```
C---LOWER LEFT CORNER ON HOLE
C
C       CALL RHOS(BETA(23),DELRHO(23))
C
      CALL HOLE(BETA4,EDG(1,4),VDUM)
C
                RAD4 = SQRT(EDG(2,4)**2 + EDG(3,4)**2)
                ANG4 = ACOS(EDG(2,4)/RAD4)
C
C---EDGE SEGMENT COORDINATES ------------------------------------------
C
      SEGMAX(1,1, 1) =  XMAX11
      SEGMAX(2,1, 1) =  RADII*STH
      SEGMAX(3,1, 1) = -RADII*CTH
C
      SEGMAX(1,2, 1) =  XMAX31
      SEGMAX(2,2, 1) =  RMAX31*STH
      SEGMAX(3,2, 1) = -RMAX31*CTH
C
      SEGMAX(1,1, 3) =  XMAX13
      SEGMAX(2,1, 3) =  RMAX13*STH
      SEGMAX(3,1, 3) = -RMAX13*CTH
C
      SEGMAX(1,2, 3) =  XMAX23
      SEGMAX(2,2, 3) =  RMAX13*STH
      SEGMAX(3,2, 3) = -RMAX13*CTH
C
      SEGMAX(1,3, 3) =  XMAX311
      SEGMAX(2,3, 3) =  RMAX311*STH
      SEGMAX(3,3, 3) = -RMAX311*CTH
C
      SEGMAX(1,4, 3) =  XMAX411
      SEGMAX(2,4, 3) =  RMAX411*STH
      SEGMAX(3,4, 3) = -RMAX411*CTH
C
C
      SEGMAX(1,1, 7) = XLO
      SEGMAX(2,1, 7) = RADOO*CTHE2
      SEGMAX(3,1, 7) = RADOO*STHE2
C
      SEGMAX(1,2, 7) = XLO
      SEGMAX(2,2, 7) = RADOO*COS(ANG3)
      SEGMAX(3,2, 7) = RADOO*SIN(ANG3)
C
      SEGMAX(1,1, 8) = 0.0
      SEGMAX(2,1, 8) = RADIO*CTHE2
      SEGMAX(3,1, 8) = RADIO*STHE2
C
C
      SEGMAX(1,2, 8) = 0.0
      SEGMAX(2,2, 8) = RADIO*CTHE3
      SEGMAX(3,2, 8) = RADIO*STHE3
C
      SEGMAX(1,1, 9) = XMAX11
      SEGMAX(2,1, 9) = 0.0
      SEGMAX(3,1, 9) = RADII
C
      SEGMAX(1,2, 9) = XMAX31
      SEGMAX(2,2, 9) = 0.0
      SEGMAX(3,2, 9) = RMAX31
```

```
C
      SEGMAX(1,1,11) = XMAX13
      SEGMAX(2,1,11) = 0.0
      SEGMAX(3,1,11) = RMAX13
C
      SEGMAX(1,2,11) = XMAX23
      SEGMAX(2,2,11) = 0.0
      SEGMAX(3,2,11) = RMAX13
C
      SEGMAX(1,3,11) = XMAX33
      SEGMAX(2,3,11) = 0.0
      SEGMAX(3,3,11) = RMAX13
C
      SEGMAX(1,4,11) = XMAX43
      SEGMAX(2,4,11) = 0.0
      SEGMAX(3,4,11) = RMAX13
C
C---DESCRIPTION OF COORDINATES ON SURFACE WITH HOLE (SIDE 4)------------
C
      DO 130 J = 1,3
C
            PL(J,1,1) = POINT(J,4)
            PL(J,2,1) = SEGMAX(J,1,3)
            PL(J,3,1) = SEGMAX(J,2,3)
            PL(J,4,1) = SEGMAX(J,3,3)
            PL(J,5,1) = SEGMAX(J,4,3)
            PL(J,6,1) = POINT(J,3)
C
            PL(J,1,2) = SEGMAX(J,1,8)
            PL(J,4,2) = EDG(J,1)
            PL(J,5,2) = EDG(J,2)
            PL(J,6,2) = SEGMAX(J,1,7)
C
            PL(J,1,3) = SEGMAX(J,2,8)
            PL(J,4,3) = EDG(J,4)
            PL(J,5,3) = EDG(J,3)
            PL(J,6,3) = SEGMAX(J,2,7)
C
            PL(J,1,4) = POINT(J,8)
            PL(J,2,4) = SEGMAX(J,1,11)
            PL(J,3,4) = SEGMAX(J,2,11)
            PL(J,4,4) = SEGMAX(J,3,11)
            PL(J,5,4) = SEGMAX(J,4,11)
  130       PL(J,6,4) = POINT(J,7)
C
            PL(1,2,2) = XMAX13
            PL(2,2,2) = RMAX13*CTHE2
            PL(3,2,2) = RMAX13*STHE2
C
            PL(1,3,2) = XMAX23
            PL(2,3,2) = RMAX13*CTHE2
            PL(3,3,2) = RMAX13*STHE2
C
            PL(1,2,3) = XMAX13
            PL(2,2,3) = RMAX13*CTHE3
            PL(3,2,3) = RMAX13*STHE3
C
            PL(1,3,3) = XMAX23
            PL(2,3,3) = RMAX13*CTHE3
            PL(3,3,3) = RMAX13*STHE3
```

```
C
C
C---EDGE NODE DISTRIBUTION-------------------------------------------------
C
        ETAMAX(1, 1) = 12.0
        ETAMAX(2, 1) = 44.0
C
        ETAMAX(1, 3) =  5.0
        ETAMAX(2, 3) = 10.0
        ETAMAX(3, 3) = 19.0
        ETAMAX(4, 3) = 48.0
C
        ETAMAX(1, 9) = 12.0
        ETAMAX(2, 9) = 44.0
C
        ETAMAX(1,11) =  5.0
        ETAMAX(2,11) = 13.0
        ETAMAX(3,11) = 19.0
        ETAMAX(4,11) = 48.0
C
      DO 140 K = 7,8
C
        ETAMAX(1, K) = 25.0
  140   ETAMAX(2, K) = 68.0
C
C
      RETURN
C***********************************************************************
C     ZONE 3 (DUCT)
C***********************************************************************
C
  200 CONTINUE
      GO TO (500,500,201,300,300,201) IZINDEX
C
  201 CONTINUE
C
      IF(IZONE.GT.3) GO TO 300
C
      DO 205 I=1,8
      DO 205 J=1,6
      COEFS(I,J) = 0.0
C
      DO 205 K=1,12
  205 COEFE(I,J,K) = 0.0
C
C---CORNER POINT COORDINATES ON HOLE-------------------------------------
C
      DO 210 J=1,3
C
          POINT(J,1) = PL(J,4,2)
          POINT(J,2) = PL(J,5,2)
          POINT(J,6) = PL(J,5,3)
  210     POINT(J,5) = PL(J,4,3)
C
C---CORNER POINT COORDINATES ON EXIT PLANE------------------------------
C
      CALL DEXIT(BETA1,POINT(1,4),VDUM)
C
      CALL DEXIT(BETA2,POINT(1,3),VDUM)
C
```

```
      CALL DEXIT(BETA3,POINT(1,7),VDUM)
C
      CALL DEXIT(BETA4,POINT(1,8),VDUM)
C
C---EDGE COEFFICIENTS ALONG HOLE (MAP = 7)----------------------------
C
       COEFE(1,1, 1) = BETA1
       COEFE(2,1, 1) = BETA2
C
       COEFE(1,1, 5) = BETA1
       COEFE(2,1, 5) = BETA4
C
       COEFE(1,1, 6) = BETA2
       COEFE(2,1, 6) = BETA3 - 2.0*PI
C
       COEFE(1,1, 9) = BETA4
       COEFE(2,1, 9) = BETA3
C
C---EDGE COEFFICIENTS ALONG DUCT (MAP = 9)----------------------------
C
       COEFE(1,1, 2) = BETA2
C
       COEFE(1,1, 4) = BETA1
C
       COEFE(1,1,10) = BETA3
C
       COEFE(1,1,12) = BETA4
C
C---EDGE COEFFICIENTS ALONG EXIT ELLIPSE (MAP = 8)--------------------
C
       COEFE(1,1, 3) = BETA1
       COEFE(2,1, 3) = BETA2
C
       COEFE(1,1, 7) = BETA2
       COEFE(2,1, 7) = BETA3 - 2.0*PI
C
       COEFE(1,1, 8) = BETA1
       COEFE(2,1, 8) = BETA4
C
       COEFE(1,1,11) = BETA4
       COEFE(2,1,11) = BETA3
C
C---SEGMENT MAXIMUMS ALONG DUCT (CIRCULAR ARCS)-----------------------
C
                   ISEG = 1
                  RATIO = -1.0
C
      DO 250 J=1,4
                  IEDGE = 4
        IF(J.EQ.2) IEDGE = 2
        IF(J.EQ.3) IEDGE = 10
        IF(J.EQ.4) IEDGE = 12
C
               EDG(1,J) = COEFE(1,ISEG,IEDGE)
      MAPSEG(ISEG,IEDGE) = 9
C
      CALL EMAP(IEDGE,ISEG,RATIO,EDG(1,J),VDUM)
C
      DO 240 I=1,3
  240 SEGMAX(I,ISEG,IEDGE) = EDG(I,J)
```

```
C
                     MAXETA = 0.65*NMBRNDS(2)
         ETAMAX(ISEG,IEDGE) = MAXETA
C
       SEGMAX(4,ISEG,IEDGE) = TXY
  250  SEGMAX(5,ISEG,IEDGE) = TXZ
C
C---SURFACE COEFFICIENTS-------------------------------------------------
C
            COEFS(1,1) = BETA1
            COEFS(2,1) = BETA2
            COEFS(3,1) = ETAMAX(1,2)
C
            COEFS(1,3) = BETA4
            COEFS(2,3) = BETA3
            COEFS(3,3) = ETAMAX(1,12)
C
            COEFS(1,5) = BETA1
            COEFS(2,5) = BETA4
            COEFS(3,5) = ETAMAX(1,4)
C
            COEFS(1,6) = BETA2
            COEFS(2,6) = BETA3 - 2.*PI
            COEFS(3,6) = ETAMAX(1,10)
C
      RETURN
C**********************************************************************
C     ZONE 4 & 5 (TURN AROUND DUCT)
C**********************************************************************
C
  300 CONTINUE
C
      GO TO (500,500,500,301,301,301) IZINDEX
C
  301 CONTINUE
C
      IF(IZINDEX.GE.4.AND.IZONE.EQ.2)GO TO 350
C
      IF(IZONE.GT.4) GO TO 350
C
C---INITIALIZE INPUT FOR ZONE 3 TO ZERO---------------------------------
C
      DO 325 N = 1,8
C
      DO 310 M = 1,5
  310    POINT(M,N) = 0.0
C
      DO 325 M = 1,6
  325    COEFS(N,M) = 0.0
C
      DO 340 N = 1,12
      DO 340 M = 1,5
C
      DO 330 J = 1,5
  330 SEGMAX(J,M,N) = 0.0
C
      DO 335 J = 1,8
  335  COEFE(J,M,N) = 0.0
C
  340   ETAMAX(M,N) = 0.0
```

```
C
C---INITIALIZE CONSTANTS-----------------------------------------------
C
C---POINT 1: ENTRANCE
C
  350         XTADI = -2.76
C
                RDO =  5.6
C
C---POINT 4: ENTRANCE
C
                RDI = 4.56
C
C---INNER CIRCULAR ARC
C
              RTADI = 0.4570
C
                XCI = -4.331
C
                RCI = RDO + RTADI
C
              RWI21 = RDO + 2.0*RTADI
C
C---OUTER CIRCULAR ARC
C
              RTADO =  1.36
C
                XCO = -4.35
C
                RCO = RDI + RTADO
C
C---TAD EXIT
C
              XTADO = 0.0
C
C---TANGENCY POINT ON OUTER SURFACE
C
              CALL TADWALL
C
C---ANGLE 1
C
             THETAX = 15.0
C
                THX = THETAX/RADDEG
                CTH = COS(THX)
                STH = SIN(THX)
C
C---ANGLE 2
C
               CTH1 = COS(THE2)
               STH1 = SIN(THE2)
C
C---ANGLE 3
C
               CTH4 = COS(THE3)
               STH4 = SIN(THE3)
C
             THETAC = 90.0 - THETAX
C
              ANG1C = 90.0 - THETAD2
```

```
               ANG4C = 90.0 - THETAD3
C***********************************************************************
C     ZONE 4 (TURN AROUND DUCT)
C***********************************************************************
C
      IF(IZINDEX.GE.4.AND.IZONE.EQ.2)GO TO 400
C
      IF(IZONE.GT.4) GO TO 400
C
C---EDGE COEFFICIENTS---------------------------------------------------
C
C---EDGE 1: CIRCULAR ARC
C
       COEFE(1,2, 1) =  XCI
       COEFE(3,2, 1) = -RCI
C
C---EDGE 3: CIRCULAR ARC
C
       COEFE(1,2, 3) =  XCO
       COEFE(3,2, 3) = -RCO
C
C---EDGE 9: CIRCULAR ARC
C
       COEFE(1,2, 9) =  XCI
       COEFE(3,2, 9) =  RCI
C
C---EDGE 11: CIRCULAR ARC
C
       COEFE(1,2,11) =  XCO
       COEFE(3,2,11) =  RCO
C
C---EDGE   : CIRCULAR ARC
C
      DO 360 J = 1,4
C
       COEFE(1,J, 5) = XTADI
       COEFE(1,J, 8) = XTADI
       COEFE(1,J, 6) = XCI - RTADI
  360  COEFE(1,J, 7) = XCO - RTADO
C
C---SURFACE COEFFICIENTS------------------------------------------------
C
          COEFS(4,2) = 1.0
          COEFS(7,2) = 3.0
C
          COEFS(4,4) = 1.0
          COEFS(7,4) = 3.0
C
          COEFS(4,6) = 1.0
          COEFS(7,6) = 3.0
C
C---CORNER POINT COORDINATES--------------------------------------------
C
          POINT(1,1) =  XTADI
          POINT(2,1) =  0.0
          POINT(3,1) = -RDO
C
          POINT(1,2) =  XCI - RTADI
          POINT(2,2) =  0.0
          POINT(3,2) = -RCI
```

```
C
      SEGMAX(2,2, 7) =  RCO*CTH1
      SEGMAX(3,2, 7) =  RCO*STH1
C
      SEGMAX(2,3, 7) =  RCO*CTH4
      SEGMAX(3,3, 7) =  RCO*STH4
C
      SEGMAX(2,1, 8) =  RDI*CTH
      SEGMAX(3,1, 8) = -RDI*STH
C
      SEGMAX(2,2, 8) =  RDI*CTH1
      SEGMAX(3,2, 8) =  RDI*STH1
C
      SEGMAX(2,3, 8) =  RDI*CTH4
      SEGMAX(3,3, 8) =  RDI*STH4
C
      SEGMAX(1,1, 9) =  XCI
      SEGMAX(3,1, 9) =  RDO
C
      SEGMAX(1,1,11) =  XCO
      SEGMAX(3,1,11) =  RDI
C
C---EDGE NODE DISTRIBUTION----------------------------------------------
C
        ETAMAX(1, 1) =  13.0
        ETAMAX(1, 3) =  13.0
        ETAMAX(1, 9) =  13.0
        ETAMAX(1,11) =  13.0
C
      DO 380 J = 7,8
C
        ETAMAX(1, J) = 36.0
        ETAMAX(2, J) = 60.0
  380   ETAMAX(3, J) = 103.0
C
        ETAMAX(1,5) = 36
        ETAMAX(1,6) = 36
C
      RETURN
C***********************************************************************
C     DATA FOR ZONE 5 (TURN AROUND DUCT)
C***********************************************************************
C---INITIALIZE EDGE COEFFICIENTS----------------------------------------
C
  400  COEFE(1,2, 1) = 0.0
       COEFE(3,2, 1) = 0.0
C
       COEFE(1,2, 3) = 0.0
       COEFE(3,2, 3) = 0.0
C
       COEFE(1,2, 9) = 0.0
       COEFE(2,2, 9) = 0.0
       COEFE(3,2, 9) = 0.0
C
       COEFE(1,2,11) = 0.0
       COEFE(2,2,11) = 0.0
       COEFE(3,2,11) = 0.0
C
C---EDGE COEFFICIENTS---------------------------------------------------
C
```

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```
C---EDGE 1: CIRCULAR ARC
C
       COEFE(1,1, 1) =  XCI
       COEFE(3,1, 1) = -RCI
C
C---EDGE 3: CIRCULAR ARC
C
       COEFE(1,1, 3) =  XCO
       COEFE(3,1, 3) = -RCO
C
C---EDGE 9: CIRCULAR ARC
C
       COEFE(1,1, 9) =  XCI
       COEFE(3,1, 9) =  RCI
C
C---EDGE 11: CIRCULAR ARC
C
       COEFE(1,1,11) =  XCO
       COEFE(3,1,11) =  RCO
C
C---EDGE  : CIRCULAR ARC
C
      DO 410 J = 1,4
C
        COEFE(1,J,5) =  XCI - RTADI
        COEFE(1,J,8) =  XCO - RTADO
        COEFE(1,J,6) =  XTADO
  410   COEFE(1,J,7) =  XTADO
C
C---SURFACE COEFFICIENTS------------------------------------------------
C
          COEFS(1,2) = 0.0
          COEFS(4,2) = 1.0
          COEFS(7,2) = 3.0
C
          COEFS(1,4) = 0.0
          COEFS(4,4) = 1.0
          COEFS(7,4) = 3.0
C
          COEFS(1,5) = 0.0
          COEFS(4,5) = 1.0
          COEFS(7,5) = 3.0
C
          COEFS(1,6) = 0.0
          COEFS(4,6) = 0.0
          COEFS(7,6) = 0.0
C
C---CORNER NODE COORDINATES---------------------------------------------
C
          POINT(1,1) =  XCI - RTADI
          POINT(3,1) = -RCI
C
          POINT(1,2) =  XTADO
          POINT(3,2) = -RADII
C
          POINT(1,3) =  XTADO
          POINT(3,3) = -RADIO
C
          POINT(1,4) =  XCO - RTADO
          POINT(3,4) = -RCO
```

```
C
          POINT(1,5) =  XCI - RTADI
          POINT(3,5) =  RCI
C
          POINT(1,6) =  XTADO
          POINT(3,6) =  RADII
C
          POINT(1,7) =  XTADO
          POINT(3,7) =  RADIO
C
          POINT(1,8) =  XCO - RTADO
          POINT(3,8) =  RCO
C
C---EDGE SEGMENT COORDINATES------------------------------------------
C
      SEGMAX(1,1, 1) =  XCI
      SEGMAX(3,1, 1) = -RWI21
C
      SEGMAX(1,2, 1) = -2.128
      SEGMAX(3,2, 1) = -6.514
C
      SEGMAX(1,1, 3) =  XWO21
      SEGMAX(3,1, 3) = -RWO21
C
      SEGMAX(1,2, 3) = -2.2
      SEGMAX(3,2, 3) = -7.5
C
      DO 420 J = 1,3
C
      SEGMAX(1,J, 5) =  XCI - RTADI
  420 SEGMAX(1,J, 8) =  XCO - RTADO
C
      SEGMAX(2,1, 5) =  RCI*CTH
      SEGMAX(3,1, 5) = -RCI*STH
C
      SEGMAX(2,2, 5) =  RCI*CTH1
      SEGMAX(3,2, 5) =  RCI*STH1
C
      SEGMAX(2,3, 5) =  RCI*CTH4
      SEGMAX(3,3, 5) =  RCI*STH4
C
      DO 440 J = 1,3
C
      SEGMAX(1,J, 6) = 0.0
  440 SEGMAX(1,J, 7) = 0.0
C
      SEGMAX(2,1, 6) =  RADII*CTH
      SEGMAX(3,1, 6) = -RADII*STH
C
      SEGMAX(2,2, 6) =  RADII*CTH1
      SEGMAX(3,2, 6) =  RADII*STH1
C
      SEGMAX(2,3, 6) =  RADII*CTH4
      SEGMAX(3,3, 6) =  RADII*STH4
C
      SEGMAX(2,1, 7) =  RADIO*CTH
      SEGMAX(3,1, 7) = -RADIO*STH
C
      SEGMAX(2,2, 7) =  RADIO*CTH1
      SEGMAX(3,2, 7) =  RADIO*STH1
```

```
C
      SEGMAX(2,3, 7) =  RADIO*CTH4
      SEGMAX(3,3, 7) =  RADIO*STH4
C
      SEGMAX(2,1, 8) =  RCO*CTH
      SEGMAX(3,1, 8) = -RCO*STH
C
      SEGMAX(2,2, 8) =  RCO*CTH1
      SEGMAX(3,2, 8) =  RCO*STH1
C
      SEGMAX(2,3, 8) =  RCO*CTH4
      SEGMAX(3,3, 8) =  RCO*STH4
C
      SEGMAX(1,1, 9) =  XCI
      SEGMAX(3,1, 9) =  RWI21
C
      SEGMAX(1,2, 9) = -2.128
      SEGMAX(3,2, 9) =  6.514
C
      SEGMAX(1,1,11) =  XWO21
      SEGMAX(3,1,11) =  RWO21
C
      SEGMAX(1,2,11) = -2.2
      SEGMAX(3,2,11) =  7.5
C
C---EDGE NODE DISTRIBUTION--------------------------------------------------
C
        ETAMAX(1, 1) =  13.0
        ETAMAX(1, 3) =  13.0
        ETAMAX(1, 9) =  13.0
        ETAMAX(1,11) =  13.0
C
        ETAMAX(2, 1) = 31.0
        ETAMAX(2, 9) = 31.0
        ETAMAX(2, 3) = 31.0
        ETAMAX(2,11) = 31.0
C
C
      DO 388 J = 7,8
C
        ETAMAX(1, J) = 36.0
        ETAMAX(2, J) = 60.0
  388   ETAMAX(3, J) = 103.0
C
        ETAMAX(1,5) = 36
        ETAMAX(1,6) = 36
C
C
  500 CONTINUE
C
      RETURN
      END
C
C***********************************************************************
C*****HGM_2*************************************************************
C***********************************************************************
C
      SUBROUTINE HOLE(B,POINT,TANGENT)
C-----------------------------------------------------------------------
C     COMPUTE COORDINATES AND DERIVATIVE FOR A POINT ON THE HOLE.
```

```
C
C     B        ANGULAR LOCATION OF A POINT ON THE HOLE
C     POINT    COORDINATES AT THE POINT
C     TANGENT  DERIVATIVE AT THE POINT
C-----------------------------------------------------------------------
C
      COMMON /DFN1/ DU1(3),DU2(3),DU3(3),DFNB,DFND,DFNF
C
      DIMENSION POINT(6),TANGENT(3),BC(3),US(3)
C
C---CALCULATE HOLE RADIUS
C
      CALL DELRAD(B,RHO,DRHO,RHOD,RDOC)
C
C---CALCULATE DUCT AXIAL DISTANCE
C
      CALL CAXIS(B,RHO,C)
C
C---ANGLULAR LOCATION OF A POINT ON THE HOLE
C
            SB = SIN(B)
            CB = COS(B)
C
C---UNIT VECTOR PERPENDICULAR FROM DUCT AXIS TO A POINT ON THE HOLE
C
         BC(1) = CB*DU2(1) + SB*DU3(1)
         BC(2) = CB*DU2(2) + SB*DU3(2)
         BC(3) = CB*DU2(3) + SB*DU3(3)
C
C---VECTOR FROM BOWL CENTER TO A POINT ON THE HOLE
C
            XD = DFNF - DFND + C*DU1(1) + RHO*BC(1)
            YD = DFNB        + C*DU1(2) + RHO*BC(2)
            ZD =               C*DU1(3) + RHO*BC(3)
C
C---COORDINATES OF A POINT ON THE HOLE
C
      POINT(1) = XD + DFND
      POINT(2) = YD
      POINT(3) = ZD
C
C---UNIT VECTOR FROM BOWL CENTER TO A POINT ON THE HOLE
C
          PMAG = SQRT(XD*XD + YD*YD + ZD*ZD)
C
         US(1) = XD/PMAG
         US(2) = YD/PMAG
         US(3) = ZD/PMAG
C
      RETURN
      END
C
C***********************************************************************
C*****HGM 2*************************************************************
C***********************************************************************
C
      SUBROUTINE DUCT(B,RHO,CAXIS,POINT)
C-----------------------------------------------------------------------
C     COMPUTE DUCT POINT = X,Y,Z FOR GIVEN B,RHO,C
C-----------------------------------------------------------------------
```

```
C
      COMMON /DFN1/ DU1(3),DU2(3),DU3(3),DFNB,DFND,DFNF
C
      DIMENSION POINT(6),BC(3)
C
C---POINT ANGLE
C
            CB = COS(B)
            SB = SIN(B)
C
C---RADIAL UNIT VECTOR
C
         BC(1) = CB*DU2(1) + SB*DU3(1)
         BC(2) = CB*DU2(2) + SB*DU3(2)
         BC(3) = CB*DU2(3) + SB*DU3(3)
C
C---COORDINATES
C
      POINT(1) = DFNF + CAXIS*DU1(1) + RHO*BC(1)
      POINT(2) = DFNB + CAXIS*DU1(2) + RHO*BC(2)
      POINT(3) =        CAXIS*DU1(3) + RHO*BC(3)
C
      RETURN
      END
C
C***********************************************************************
C*****HGM 2*************************************************************
C***********************************************************************
C
      SUBROUTINE RHOS(B,DRHO)
C-----------------------------------------------------------------------
C     COMPUTE THE DIFFERENCE IN RADIUS BETWEEN DUCT AND HOLE FOR THE
C     LOWER CORNER POINTS ON THE HOLE.
C
C     B     ANGULAR LOCATION OF A POINT ON THE HOLE
C     DRHO  DIFFERENCE BETWEEN HOLE AND DUCT RADIUS
C-----------------------------------------------------------------------
C
      COMMON /DFN1/ DU1(3),DU2(3),DU3(3),DFNB,DFND,DFNF
      COMMON /DFN2/ AE,BE,DFNR,ZSTAR,AGL,BETA1,BETA2,BETA3,BETA4
      COMMON /DFN3/ AD,BD,BETA(37),DELRHO(37),RADOC(37)
C
C---TOLERANCE FOR NEWTON-RAPHSON ITERATION
C
      FEPS = 1.0E-07
C
C---ANGLE OF DUCT AXIS
C
        SA = SIN(AGL)
        CA = COS(AGL)
C
C---ANGLULAR LOCATION OF A POINT ON THE HOLE
C
        SB = SIN(B)
        CB = COS(B)
C
C---RADIUS OF ELLIPTIC DUCT
C
        FD = SQRT((AD*SB)**2 + (BD*CB)**2)
      RHOD = AD*BD/FD
```

```
C
C---INITIAL HOLE RADIUS
C
       RHO = RHOD + DRHO
C
C---DISTANCE ALONG MAJOR AXIS OF BOWL ELLIPSE--------------------------
C
   10  XMD = DFNF - DFND + ZSTAR*SA/CA + RHO*CB/CA
C
C---ELLIPSE RATIO OF BOWL
C
       BOA = BE/AE
C
C---DISTANCE ALONG MINOR AXIS OF BOWL ELLIPSE
C
        F1 = SQRT(AE**2 - XMD**2)
C
C---RADIAL DISTANCE TO HOLE
C
        F2 = DFNR + BOA*F1
C
C---VERTICAL DISTANCE TO HOLE
C
        F3 = DFNB + RHO*SB
C
C---HORIZONTAL DISTANCE TO HOLE - ZSTAR**2
C
        FR = F2**2 - F3**2 - ZSTAR**2
C
C---DERIVATIVE
C
       DF1 = BOA*XMD*CB*F2/(F1*CA)
       DF2 = F3*SB
      DFDR = -2.*(DF1 + DF2)
C
C---HOLE RADIUS
C
       RHO = RHO - FR/DFDR
C
      IF(ABS(FR).GT.FEPS) GO TO 10
C
C---DIFFERENCE IN RADIUS BETWEEN HOLE AND DUCT-------------------------
C
      DRHO = RHO - RHOD
C
      RETURN
      END
C
C*********************************************************************
C*****UTILITY*********************************************************
C*********************************************************************
C
      SUBROUTINE ANGLES(VECTOR,THETA,PHI)
C--------------------------------------------------------------------
C   CONVERTS FROM VECTOR TO ANGLES
C     THETA = THE ANGLE BETWEEN THE VECTOR
C             AND ITS PROJECTION IN THE XZ PLANE
C       PHI = THE ANGLE IN THE XZ PLANE
C--------------------------------------------------------------------
C
```

```
      COMMON /INITA/   MAPTEN,INCHES
      COMMON /INITC/   PI,RADDEG
C
      DIMENSION VECTOR(3)
C
      ONE = 1.0
C
      DO 10  I=1,3
   10 IF(ABS(VECTOR(I)).LT.0.00001) VECTOR(I) = 0.0
C
           THETA = 0.0
             PHI = 0.0
C
      CALL VMAG(VECTOR,VECMAG)
C
      IF(VECMAG.EQ.0.0) RETURN
C
   20                        VNORM2 = VECTOR(2)/VECMAG
      IF(ABS(VNORM2).GT.1.0) VNORM2 = SIGN(ONE,VNORM2)
C
                              THETA = ASIN(VNORM2)*RADDEG
                            XZPLANE = SQRT(VECTOR(1)**2 + VECTOR(3)**2)
C
      IF(XZPLANE.LT.ABS(VECTOR(2))/1000.) RETURN
C
                             VNORM3 = VECTOR(1)/XZPLANE
      IF(ABS(VNORM3).GT.1.0) VNORM3 = SIGN(ONE,VNORM3)
C
                                PHI = ACOS(VNORM3)*RADDEG
      IF(VECTOR(3).LT.0.0)      PHI = -PHI
C
      RETURN
      END
C
C
C***********************************************************************
C*****HGM 2*************************************************************
C***********************************************************************
C
      SUBROUTINE SPEDGE(SRI,SRF,EPS,SAC,SEDGE)
C-----------------------------------------------------------------------
C     CIRCULAR SUB-EDGE COORD.,SIDE 4 OF BOWL
C-----------------------------------------------------------------------
C
      DIMENSION SRI(6),SRF(6),SEDGE(6),SAC(3),VDUM(3)
      DIMENSION PC1(6),PC2(6),PVEC1(3),PVEC2(3)
      DIMENSION UN(3),UP(3),UR(3),XN(3),XP(3),XR(3)
C
      DATA PI /3.141592654/
C
      DO 10 J=1,6
      PC1(J) = SRI(J)
   10 PC2(J) = SRF(J)
C
      DO 20 J=1,3
      PVEC1(J) = PC1(J) - SAC(J)
   20 PVEC2(J) = PC2(J) - SAC(J)
C
      CALL VMAG(PVEC1,RM1)
C
```

```
      CALL VMAG(PVEC2,RM2)
C
      CALL CROSS(PVEC2,PVEC1,UN,71)
C
      CALL CROSS(PVEC1,UN,UP,72)
C
      CALL CROSS(UN,UP,UR,73)
C
      RCC = RM1*RM2
C
      CALL VDOT(PVEC1,PVEC2,RR)
C
                          THETA = PI
      IF(ABS(RR).LE.RCC) THETA = ACOS(RR/RCC)
C
          RC = 1.0/SIN(THETA)
C
      THETA1 = THETA
C
        ANG1 = (1.0 - EPS)*THETA
        ANG2 =          EPS*THETA
C
       CANG1 = COS(ANG1)
       SANG1 = SIN(ANG1)
C
       CANG2 = COS(ANG2)
       SANG2 = SIN(ANG2)
C
      DO 40 J=1,3
   40 SEDGE(J) = SAC(J) + RC*(SANG1*PVEC1(J) + SANG2*PVEC2(J))
C
      CALL VDOT(PC1(4),PC2(4),RR)
C
      IF(RR.GT.0.9999) GO TO 70
C
      CALL CROSS(PC2(4),PC1(4),XN,74)
C
      CALL CROSS(PC1(4),XN,XP,75)
C
      CALL CROSS(XN,XP,XR,76)
C
      THET = ACOS(RR)
      ALPH = EPS*THET
C
      CANG = COS(ALPH)
      SANG = SIN(ALPH)
C
      CALL VADD(CANG,XR,SANG,XP,VDUM,SEDGE(4))
C
      RETURN
C
   70 CONTINUE
C
      DO 80 J=1,3
   80 SEDGE(J+3) = PC1(J+3)
C
      RETURN
C
      END
C
```

```
C
C*************************************************************************
C*****HGM_2***************************************************************
C*************************************************************************
C
      SUBROUTINE TADWALL
C-------------------------------------------------------------------------
C     COMPUTE TANGENT POINT ON OUTER TAD WALL
C-------------------------------------------------------------------------
C
      COMMON /DFN6/ RTADI,RTADO,RCI,RCO,RDI,RDO,XCI,XCO,XTADI,XTADO
      COMMON /DFN7/ RWO21,XWO21,RADII,RADIO
C
       TASQ = (XTADO - XCO)**2 + (RADIO - RCO)**2 - RTADO**2
        TAL = SQRT(TASQ)
        ETA = TAL/RTADO
      ETASQ = ETA**2
C
        A = 1.0 + ETASQ
        B = RADIO + ETASQ*RCO
      BSQ = B**2
C
        C = TASQ - RADIO**2 - ETASQ*RCO**2
      DSQ = 1.0 + (A*C/BSQ)
C
        D = SQRT(DSQ)
C
      RWO21 = B*(1.0 + D)/A
      XWO21 = XTADO - (RWO21 - RCO)*ETA
C
      RETURN
      END
C
```

Appendix D
HGM OUTPUT REWRITE LISTING

```
C
      SUBROUTINE REWRITE
C-----------------------------------------------------------------------
C
C    THIS PROGRAM CONVERTS HGM2DUCT CODE GEOMETRY FILES TO
C    PLOT3D GEOMETRY FILES
C
C-----------------------------------------------------------------------
      DIMENSION IDIM(110),JDIM(110),KDIM(110)
      DIMENSION XBUF(200000),YBUF(200000),ZBUF(200000)
C-----------------------------------------------------------------------
      MATE = 0
C
C---ASSIGN UNITS
C
      DATA I20,INPUT,ISCR,IP3D /1,2,3,4/
C
      OPEN(UNIT=I20,FILE='HGM2DUCT.DAT',STATUS='OLD')
      OPEN(UNIT=INPUT,FILE='REWRITE.OUT',STATUS='NEW')
      OPEN(UNIT=ISCR,STATUS='SCRATCH',FORM='UNFORMATTED')
C
C---COUNTERS
C
         I2 = 0
      NGRID = 0
C
C---READ PARAMETERS FROM GEOMETRY
C
       IERR = 1
C
      READ(I20,1000,END=200) NSTORE,IPLN,
     &                  INOD2,JNOD2,KNOD2,MARCH2
C
C---WRITE DATA RANGE
C
      I1 = I2 + 1
      I2 = I2 + NSTORE
C
      WRITE(INPUT,1210)
      WRITE(INPUT,1220) NSTORE,IDYN,IPLN,INOD2,JNOD2,KNOD2,
     &                  MARCH2,I1,I2
C-----------------------------------------------------------------------
C   READ X,Y & Z FROM GEOMETRY
C-----------------------------------------------------------------------
        IERR = 2
C
      READ(I20,1010,ERR=400) (XBUF(I),I=I1,I2)
C
        IERR = 3
C
      READ(I20,1010,ERR=400) (YBUF(I),I=I1,I2)
C
        IERR = 4
C
      READ(I20,1010,ERR=400) (ZBUF(I),I=I1,I2)
C
        IERR = 5
C
      IPLANE = 1
C
```

```
C---READ NEXT SET OF PARAMETERS FROM GEOMETRY
C
  100 READ(I20,1000,END=200) NSTORE,IPLN,INOD,JNOD,KNOD,MATE,MARCH
C
C---CHECK FOR NEW ZONE-------------------------------------------------
C
      IF(INOD.NE.INOD2 .OR. JNOD.NE.JNOD2 .OR. KNOD.NE.KNOD2) THEN
C
      IF(MARCH2.EQ.1 .AND. JNOD.EQ.JNOD2 .AND. KNOD.EQ.KNOD2) GO TO 110
      IF(MARCH2.EQ.2 .AND. INOD.EQ.INOD2 .AND. KNOD.EQ.KNOD2) GO TO 110
      IF(MARCH2.EQ.3 .AND. JNOD.EQ.JNOD2 .AND. INOD.EQ.INOD2) GO TO 110
C
      NGRID = NGRID + 1
C
      IF(MARCH2.EQ.1) THEN
C
                            INOD2 = IPLANE
                    IDIM(NGRID) = KNOD2
                    JDIM(NGRID) = JNOD2
                    KDIM(NGRID) = INOD2
C
                    END IF
C
      IF(MARCH2.EQ.2) THEN
C
                            JNOD2 = IPLANE
                    IDIM(NGRID) = INOD2
                    JDIM(NGRID) = KNOD2
                    KDIM(NGRID) = JNOD2
C
                    END IF
C
      IF(MARCH2.EQ.3) THEN
C
                            KNOD2 = IPLANE
                    IDIM(NGRID) = JNOD2
                    JDIM(NGRID) = INOD2
                    KDIM(NGRID) = KNOD2
C
                    END IF
C
      WRITE(INPUT,1230)
      WRITE(INPUT,1220) NGRID,IDIM(NGRID),JDIM(NGRID),KDIM(NGRID)
C
       IERR = 6
C
      WRITE(ISCR,ERR=411)
     1                              (XBUF(I),I=1,I2),
     2                              (YBUF(I),I=1,I2),
     3                              (ZBUF(I),I=1,I2)
C
      WRITE(INPUT,1250)
C
       INOD2 = INOD
       JNOD2 = JNOD
       KNOD2 = KNOD
C
      MARCH2 = MARCH
C
      WRITE(INPUT,1210)
```

```
C
          I2 = 0
      IPLANE = 0
                                                              END IF
C
C---WRITE DATA RANGE-------------------------------------------------------
C
  110 CONTINUE
C
          I1 = I2 + 1
          I2 = I2 + NSTORE
C
      WRITE(INPUT,1220) NSTORE,IDYN,IPLN,INOD,JNOD,KNOD,MARCH,I1,I2
C
C---READ X,Y & Z FROM GEOMETRY
C
        IERR = 7
C
      READ(I20,1010,ERR=400) (XBUF(I),I=I1,I2)
C
        IERR = 8
C
      READ(I20,1010,ERR=400) (YBUF(I),I=I1,I2)
C
        IERR = 1
C
      READ(I20,1010,ERR=400) (ZBUF(I),I=I1,I2)
C
      IPLANE = IPLANE + 1
C
      GO TO 100
C
C---END OF GEOMETRY DATA---------------------------------------------------
C
  200 CONTINUE
C
                              NGRID = NGRID + 1
C
      IF(MARCH2.EQ.1) THEN
C
                              INOD2 = IPLANE
                        IDIM(NGRID) = KNOD2
                        JDIM(NGRID) = JNOD2
                        KDIM(NGRID) = INOD2
C
                        END IF
C
      IF(MARCH2.EQ.2) THEN
C
                              JNOD2 = IPLANE
                        IDIM(NGRID) = INOD2
                        JDIM(NGRID) = KNOD2
                        KDIM(NGRID) = JNOD2
C
                        END IF
C
      IF(MARCH2.EQ.3) THEN
C
                              KNOD2 = IPLANE
                        IDIM(NGRID) = JNOD2
```

```
                    JDIM(NGRID) = INOD2
                    KDIM(NGRID) = KNOD2
C
                    END IF
C
      WRITE(INPUT,1230)
      WRITE(INPUT,1220) NGRID,IDIM(NGRID),JDIM(NGRID),KDIM(NGRID)
      WRITE(INPUT,1240)
C
C---WRITE X,Y & Z ON SCRATCH FILE
C
      IERR = 10
C
      WRITE(ISCR,ERR=411)
     1                            (XBUF(I),I=1,I2),
     2                            (YBUF(I),I=1,I2),
     3                            (ZBUF(I),I=1,I2)
C
      WRITE(INPUT,1250)
C
      CLOSE(UNIT=I20)
C
      WRITE(INPUT,1260)
C
      REWIND(UNIT=ISCR)
C
      WRITE(INPUT,1270)
C-----------------------------------------------------------------------
C   WRITE BINARY FILE
C-----------------------------------------------------------------------
      OPEN(UNIT=IP3D,FILE='PLT3D.BIN',STATUS='NEW',FORM='UNFORMATTED')
C
      WRITE(INPUT,1300)
C
      IF(NGRID.GT.1) THEN
C
                    IERR = 11
C
                    WRITE(INPUT,1310)   NGRID
                    WRITE(IP3D,ERR=420) NGRID
C
                    END IF
C
      IERR = 11
C
      WRITE(INPUT,1320)
      WRITE(INPUT,1330)   (IDIM(N),JDIM(N),KDIM(N),N=1,NGRID)
C
      WRITE(IP3D,ERR=420) (IDIM(N),JDIM(N),KDIM(N),N=1,NGRID)
C
C
C---WRITE BINARY PLT3D FILE
C
C
      DO 300 N=1,NGRID
C
      IERR = 12
C
        I2 = IDIM(N)*JDIM(N)*KDIM(N)
C
```

```
      READ(ISCR,ERR=410)
     1                         (XBUF(I),I=1,I2),
     2                         (YBUF(I),I=1,I2),
     3                         (ZBUF(I),I=1,I2)
C
      IERR = 13
C
      WRITE(IP3D,ERR=420)
     1                         (XBUF(I),I=1,I2),
     2                         (YBUF(I),I=1,I2),
     3                         (ZBUF(I),I=1,I2)
C
      WRITE(INPUT,1340) N
C
  300 CONTINUE
C
C---WRITE GRID NUMBER
C
      WRITE(INPUT,1350) NGRID
C
      GO TO 500
C-------------------------------------------------------------------
C   ERRORS
C-------------------------------------------------------------------
C---ERROR READING GEOMETRY DATA FROM FILE20
C
  400 WRITE(INPUT,1400) IERR
C
      GO TO 500
C
C---ERROR READING SCRATCH FILE
C
  410 WRITE(INPUT,1410) IERR
  411 WRITE(INPUT,1411) IERR
C
      GO TO 500
C
C---ERROR WRITING TO PLOT3D BINARY FILE
C
  420 WRITE(INPUT,1420) IERR
C-------------------------------------------------------------------
C   END OF PROGRAM
C-------------------------------------------------------------------
  500 CONTINUE
C
      CLOSE(UNIT=ISCR)
      CLOSE(UNIT=IP3D)
      CLOSE(UNIT=INPUT)
C
C---FORMAT STATEMENTS
C
 1000 FORMAT(9I5)
 1010 FORMAT(6E22.14)
C
 1200 FORMAT(/' *** ERROR: RERUN GEOMN WITH MATE SET TO 0 ***')
 1210 FORMAT(/'NSTORE IDYN IPLN INOD JNOD KNOD MARCH    I1    I2')
 1220 FORMAT(1X,7I5,2I6)
 1230 FORMAT(/' NGRID IDIM JDIM KDIM ')
 1240 FORMAT(/' END OF FILE REACHED ON I20')
 1250 FORMAT(/' GRID WRITTEN TO ISCR ')
```

```
 1260 FORMAT(/' I20 CLOSED')
 1270 FORMAT(/' ISCR REWIND')
C
 1300 FORMAT(/' IP3D OPENED')
 1310 FORMAT(/'    NGRID =',I3)
 1320 FORMAT(/' IDIM JDIM KDIM ')
 1330 FORMAT(/ 3I5)
 1340 FORMAT(/' GRID ',I2,' WRITTEN TO PLT3D.BIN')
 1350 FORMAT(/' THERE ARE ',I2,' GRIDS WRITTEN TO PLT3D.BIN')
C
 1400 FORMAT(/' ERROR READING GEOMETRY DATA FROM FILE20 ON UNIT I20',I2)
 1410 FORMAT(/' ERROR READING SCRATCH FILE ON UNIT ISCR',I2)
 1411 FORMAT(/' ERROR WRITING SCRATCH FILE TO UNIT ISCR',I2)
 1420 FORMAT(/' ERROR WRITING TO PLOT3D BINARY FILE ON UNIT IP3D',I2)
C
      STOP
      END
C
```